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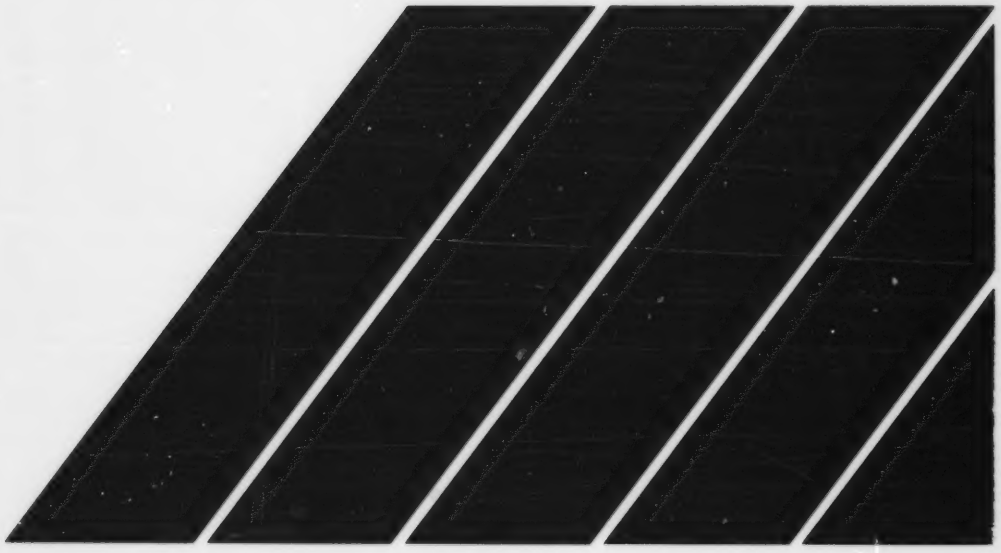
ADAMS NATURAL GAS/DIESEL DEMONSTRATION PROJECT: FINAL MONITORING REPORT



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ADAMS NATURAL GAS/DIESEL DEMONSTRATION PROJECT: FINAL MONITORING REPORT

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Efficiency and Alternative Energy Technology Branch
Energy, Mines and Resources Canada
Ottawa, Ont.

June, 1990

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ADAMS PROJECT UPDATE

August 23, 1990

Operation of the Safeway natural gas/diesel demonstration truck in recent months has been virtually trouble-free, while drivability has been greatly improved. These improvements may be attributed to two changes to the system that have been made since the end of the one-year monitoring period on April 4, 1990.

1. Installation of an Impco model HPR-501 high pressure regulator, replacing the MECO type P-1-DD multi-seat regulator. Since its installation on April 16, 1990 (577,859 km), absolutely no servicing of the Impco regulator has been required to date (August 23/90, 592,575 km), unlike the MECO regulator which required monthly seat block rotations.

2. Software reprogramming of the microprocessor controlling operation of the gas actuator valve stepper motor, reducing the response time from 10 to 5 milliseconds. Thus, it is able to respond twice as fast to changes in accelerator position. This has virtually eliminated accelerator response problems during shifting gears, as described on page 39. Drivability of the truck is now on a par with diesel operation, according to its two drivers.

With these improvements in reliability and drivability, operation of the natural gas/diesel conversion system is now judged to be satisfactory for commercial service. Only the longer-term durability remains to be proven, and the Safeway demonstration truck will continue to operate to this end.

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John F. Adams for his pioneering work in launching this demonstration project and for his continued commitment to bringing the project to a successful conclusion after retiring from management of John F. Adams & Son Ltd.

Mac Christie and Brian White of Christie/Adams Distributors Ltd. for their ongoing support of the project, and cooperation in providing fuelling records and making the natural gas fuelling station accessible to interested parties.

Lynn Ross, Greg Cripps, Bill Hennessey, and Roger Anastasiou of B.C. Gas Inc. who played key roles in initiating this project, including design and provision of fuelling stations.

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ABSTRACT

This report presents the results of a one-year program to demonstrate the viability of fuelling and operating diesel road vehicles on dual fuel natural gas/diesel under commercial operating conditions. During this project, funded under the Enerdemo Program, a natural gas fuelling station designed to accommodate the specific needs of heavy trucks was constructed, and a Canada Safeway Ltd. tractor was converted to dual fuel natural gas/diesel operation using a system developed by Cryogas Engineering Ltd. The truck accumulated more than 64,000 km during the one-year monitoring period, providing useful data in terms of comparative fuel efficiency, natural gas/ diesel proportions of fuel use, operating range, and refuelling times, along with assessments of its performance by drivers and fleet management.

RÉSUMÉ

Ce rapport fait état des résultats d'un programme échelonné sur un an ayant pour but de démontrer la viabilité de la propulsion de véhicules diesel à l'aide d'un bicarburant gaz naturel-diesel pour utilisation commerciale. Aux fins du projet financé par le programme Enerdemo, l'on a procédé à la construction d'un poste d'essence pour desservir les camions lourds, et un camion de l'entreprise Canada Safeway Ltd. a été converti au bicarburant gaz naturel-diesel selon un système développé par Cryogas Engineering Ltd. Le camion a fait plus de 64 000 km durant la période de contrôle d'un an et l'on a pu ainsi recueillir des renseignements utiles portant sur l'efficacité énergétique comparée des carburants, l'utilisation proportionnelle de gaz naturel et de diesel, le champs d'opération du camion converti, les périodes de ravitaillement en carburant et l'évaluation de la performance par les chauffeurs et les gestionnaires.

ADAMS NATURAL GAS/DIESEL DEMONSTRATION PROJECT MONITORING REPORT

EXECUTIVE SUMMARY

On May 26, 1986, John F. Adams & Son Limited (now Christie/Adams Distributors Limited), a commercial truck fuel station operator in Burnaby, British Columbia (B.C.), entered into an agreement with EMR Canada to demonstrate the technical and economic viability of fuelling and operating diesel road vehicles on natural gas/diesel under commercial operating conditions. This project was funded under the Enerdemo Canada Program.

Construction of a natural gas fuelling station at the Adams fuelling station site in Burnaby was completed in March 1987. This station has been designed as a 24-hour, 7-day per week cardlock operation to service light and heavy duty commercial vehicles. The station has been designed to accommodate line-haul trucks and trailers, provide quick filling times, provide adequate storage and recharge capabilities, and easily accommodate increased load development. It also offers cardlock fuel facilities dispensing diesel, gasoline, and propane fuels. Figure 1 (page xiv) shows the layout of the Christie/Adams natural gas fuelling station.

Subsequent to the successful start-up of the Adams fuelling station, work began to secure demonstration vehicles that would be converted to natural gas/diesel operation and monitored under the Adams project. As the first step in this process, a review was undertaken of the performance of a number of natural gas/diesel conversion systems that had been installed in vehicles in various North American locations. Ultimately, the project team selected the microprocessor-controlled, aspirated natural gas conversion system developed by Cryogas Engineering Ltd. of Vancouver, B.C.

Cummins British Columbia was then approached to act as the prime contractor for the conversion and provide ongoing technical support. The company agreed to act in these capacities, as well as to provide a backup warranty which assured the owners of converted vehicles that their normal

warranties would not be voided or limited if their engines were converted to natural gas operation. The backing of a major engine distributor was considered essential in order to secure participants, as a survey of fleet operators in the vicinity of the Adams fuelling station indicated that they would be extremely reluctant to have their vehicles converted without the sanction and support of the engine manufacturer or distributor.

The truck department of Safeway Canada Limited, located in Burnaby, B.C., subsequently was approached and signed an agreement to have one of its trucks converted to natural gas/diesel operation using the Cryogas system.

The Safeway truck converted to natural gas/diesel operation for this demonstration project is a 1984 Freightliner cabover tractor hauling trailers up to 53 feet in length, with a gross vehicle weight of up to 47,000 kg. This truck typically runs from Burnaby to the Interior twice weekly, most often turning around at Prince George. Inland Natural Gas (now B.C. Gas Inc.) agreed to install a natural gas fuelling station at the key junction point of Cache Creek, B.C., in order to provide the demonstration vehicle with an intermediate fuelling location.

The original high-mileage 350 HP Cummins Big Cam III engine in the truck was replaced with a factory-reconditioned 350 HP Big Cam IV prior to conversion, and broken in on straight diesel for 9,000 km. Conversion of the truck was undertaken during February 1989. At this time a microprocessor-controlled natural gas/diesel conversion system was installed by Cryogas Engineering. At the same time, a compressed natural gas storage system of 612 litres water capacity was mounted on the truck. This volume of storage can accommodate roughly 100 kilograms of natural gas, equal to about 134 litres of diesel fuel on a lower heating value basis. The fuelling system can accommodate two fuelling probes at the same time on either side of the truck, in an effort to reduce fill times and increase the ease of refuelling. Figure 2 (page xiv) shows the demonstration vehicle following its conversion to natural gas/diesel operation.

The truck underwent testing during March 1989 before going into commercial service during the next month. Monitoring of the operation of

the demonstration truck began on April 6, 1989. By the end of the one-year monitoring period (April 4, 1990), the truck had accumulated a total of 64,000 km, of which 65 percent were on natural gas/diesel. The truck could have operated a much higher percentage of the distance on natural gas/diesel, but was operated on straight diesel for a considerable distance in order to provide a benchmark against which to compare its performance on dual fuel natural gas/diesel operation. When operating in the dual fuel mode, the truck consistently averaged about 60 percent natural gas and 40 percent diesel. During operation on natural gas/diesel on highway routes, a 15 percent loss in thermal efficiency was experienced relative to straight diesel operation.

Drivers of the demonstration vehicle identified a number of performance factors which needed to be addressed before the vehicle conversion and refuelling systems would be acceptable to the commercial trucking industry:

1. **Increased fuelling time** was identified as a significant inconvenience, particularly for the highway driver. Driver fuelling time per two-day round trip to the Interior was increased by up to 2 hours relative to straight diesel. In response to the problem, improvements aimed at reducing fill times were made at several natural gas fuelling stations.

2. **Reduced range.** The range of the truck on dual fuel is limited to about 350 km when operating on highway routes versus in excess of 2,000 km prior to conversion. This necessitates more frequent refuelling if natural gas utilization is to be maximized. In any event, the truck has sufficient diesel storage to travel another 1,000 km on highway runs after natural gas storage has been exhausted.

3. **Accelerator response problems.** Drivers generally agree that the accelerator response on dual fuel was noticeably lagged compared to operation on straight diesel. In an effort to improve response, the natural gas intake and actuator valve have been moved from the back of the truck cab to a position immediately upstream from the turbocharger, while reprogramming of the on-board computer has also

been undertaken. Some degree of hesitation still persists in spite of these changes.

Reprogramming of the on-board computer to address the foregoing problem, however, appears to have to produced another response problem which occurs when the driver shifts to a higher gear. Unlike diesel operation, the engine speed is slow to drop when the driver takes his foot off the accelerator during operation in the dual fuel mode. He therefore has to wait longer for the engine speed to drop before he is able to shift to a higher gear.

Drivers indicated that the natural gas conversion system use on the Safeway truck needs further development work before it would be acceptable in commercial service, particularly with respect to overcoming the accelerator response problems. Safeway's fleet management also identified a number of other factors as being necessary to make the system acceptable to a fleet operation:

- a more reliable first-stage regulator;
- a lighter natural gas fuel storage system;
- more natural gas fuelling stations with better access for highway trucks;
- quicker fill times at natural gas fuelling stations.

A different first-stage regulator has since been installed and so far has proven more reliable than the original unit. Safeway plans to continue to operate the demonstration truck with the goal of proving the viability of the system over the longer term.

Fuel cost savings resulting from the substitution of natural gas for diesel fuel were not large in the case of the Safeway truck, given the increased level of fuel consumption and the purchase of natural gas at higher prices than if the fleet were to have its own natural gas fuelling station. The analysis in Section 7 of this report shows that at fleet natural gas prices, fuel cost savings could be substantially increased. Improvements in thermal efficiency relative to straight diesel operation and higher levels of natural gas utilization (attainable through refinements to dual fuel systems or the

use of monofuel spark-ignition natural gas engines) would further improve the economics of natural gas use in heavy trucks. Even with present technology, however, the use of natural gas in high-mileage trucks may provide a conversion cost payback of less than 2 years.

For natural gas to emerge as a significant fuel for heavy trucks, however, developments must take place to address a number of current impediments. These include:

1. The availability of a suitable natural gas engine (complete with full warranty coverage) from a major engine manufacturer.

2. Support and service from a major organization.

3. The availability of natural gas storage cylinders (suitable for heavy truck applications) that are fully approved by the appropriate regulatory authorities.

4. Continued engine development leading to improvements in fuel efficiency, emissions, and higher levels of diesel fuel substitution.

5. The development of new fuelling infrastructure for natural gas-fuelled highway trucks.

While indicating that further developments, as detailed in the foregoing list, must take place if natural gas is to emerge as a significant fuel for heavy trucks, this demonstration project has achieved a number of important objectives:

1. Provided good quality data on relative natural gas/diesel versus straight diesel fuel efficiency (15 percent loss on highway trips), gas/diesel proportions of fuel use (60 percent natural gas), and operating range during on-road operation of a Class 8 highway tractor (350 km).

2. Demonstrated the successful operation of a natural gas fuelling station specifically designed to satisfy the particular needs of heavy trucks in terms of accessibility and reduced fuelling times.

3. Greatly raised the profile of natural gas as a potential fuel for heavy trucks, generating both international as well as local interest in the demonstration.

4. Showed that natural gas is a safe and viable fuel for heavy trucks, allaying some initial concerns by drivers, maintenance staff, and management. After participating in this demonstration project, Safeway management has expressed potential interest in acquiring up to 10 spark-ignition natural gas fuelled tractors that would operate on local routes.

Thus, the John Adams natural gas/diesel demonstration project has achieved its major objectives, as detailed in Section 1.1 of this report.

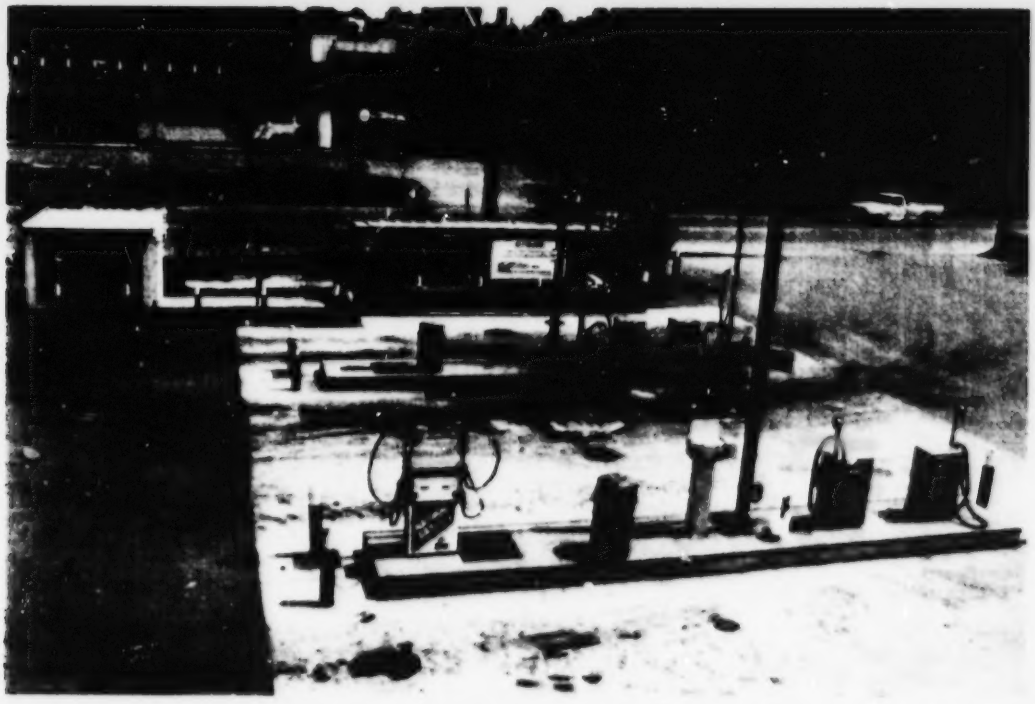

Figure 1: Christie Adams Natural Gas Fuelling Station, Burnaby, B.C.

Figure 2: Natural Gas/Diesel Demonstration Truck - Safeway Unit B121

ADAMS NATURAL GAS/DIESEL DEMONSTRATION PROJECT
MONITORING REPORT

1.0 INTRODUCTION

1.1 Project Background and Objectives

Since the introduction of natural gas as a vehicle fuel in Canada during the early 1980's, British Columbia has been a leader in the development of fuelling infrastructure, vehicle conversions, and research and development related to both vehicle and fuelling station equipment. While the technology for conversion of gasoline-engined cars and light trucks to natural gas operation is well-established, the operation of diesel-fuelled heavy trucks and buses on natural gas is still not commercialized. Such vehicles are attractive candidates for conversion to natural gas operation for two reasons:

1. They have the potential to achieve larger annual fuel cost savings than gasoline-powered cars and light trucks by virtue of their high volume of fuel consumption. There are many highway trucks in B.C., for example, that consume in excess of 200,000 litres of fuel annually.

2. Diesel engines will likely have problems meeting emissions standards due to be implemented during the early 1990's. It is generally recognized that natural gas has the potential to greatly reduce particulate emissions in diesel engines relative to those produced from operation on straight diesel fuel.

By the mid-1980's at least three organizations in the Vancouver area had undertaken research and development work leading to the conversion of diesel engines to natural gas/diesel dual fuel operation. However, only limited data of variable quality were available concerning on-road performance of the vehicles that were converted.

Recognizing the potential for development of this market, John F. Adams & Son Limited, a commercial truck fuel station operator in Burnaby, on May 26, 1986 entered into an agreement with EMR Canada to demonstrate the technical and economic viability of fuelling and operating diesel road vehicles on natural gas/diesel under commercial operating conditions. This project, which was funded under the Enerdemo Canada Program, has the following specific objectives:

- to demonstrate new technology and prove its commercial viability;
- to demonstrate a prototype commercial CNG/diesel fuelling station;
- to accelerate development of diesel conversion technology and establish credibility in the market;
- to provide the needed incentive to get the diesel market established;
- to gain design and field operations experience with dual fuel natural gas/diesel conversions.

B.C. Gas Inc. (formerly B.C. Hydro Gas Division) played a key role in initiating this demonstration project, and has made invaluable on-going contributions of both equipment and technical support.

The primary purpose of this report is to provide detailed documentation of technical and economic parameters relating to the conversion and operation of demonstration vehicles. In addition, the process leading up to the conversion of demonstration vehicles to natural gas/diesel is also chronicled, as it may be of interest to some readers.

1.2 Market Research Report

As the first step selecting candidate vehicles to participate in the demonstration project, Canadian Resourcecon was retained to undertake market research in two main areas:

1. Identify the types of engines, vehicles, and fleets that would be most suitable for conversion, from both economic and operational perspectives.

2. Identify specific fleets interested in converting vehicles to natural gas/diesel under this project, as well as the conditions under which they would be willing to convert.

To establish this information approximately 40 truck fleet operators in the greater Vancouver area of B.C. were contacted, along with major truck and engine dealers. The complete findings of this research, undertaken between October 1986 and February 1987, are reported in a study entitled "Market Research Report: John F. Adams & Son Ltd. Natural Gas/Diesel Enerdemo Project" (Canadian Resourcecon Ltd., May 1987).

The major conclusions and recommendations of this report were as follows:

1. **Types of engines to convert:** Cat 3406B and Cummins 855 cubic inch Big Cam IV, 400 HP and up. In priorizing engines, consideration was given not only to the prevalence of these engines in the existing stock of vehicles in British Columbia and models which are likely to become popular in the future, but also to their relative levels of fuel consumption. Higher horsepower engines are obviously more attractive candidates for conversion from an economic perspective than their lower horsepower counterparts.

2. **Types of fleets and duty cycles to convert:** In order to maximize diesel fuel displacement by natural gas, the best candidates for conversion are high kilometrage trucks which operate on fixed routes where natural gas fuelling is available. Ideally, both line-haul and short-haul trucks should participate in the demonstration to determine the suitability of natural gas in a variety of diesel truck applications. Aside from tractors, conversion of Class 8 straight trucks, including vans and dump trucks would also be of interest.

3. **Engine warranty:** based upon discussions with fleet operators, it became quite clear that some means of ensuring that truck owners are protected

from financial loss in the event of engine damage caused by alterations to the stock engine must be provided if operators are to be induced to participate in the demonstration project. With new Class 8 engines typically valued at $25,000 and rebuilt engines costing half that amount, the trend is for truck operators to opt for extended warranty coverage. Fleet operators were understandably concerned about what would happen to their warranty coverage if an engine failure were attributed to the natural gas fuelling system.

4. **Conversion cost:** from discussions with fleet operators, it also became apparent that the originally-proposed maximum grant of $5,000 per vehicle would be inadequate to interest many fleet operators in participating in the project. Instead, given the risk of downtime and the "hassle factor" involved with an unproven system and monitoring reporting requirements, most operators indicated that they were unwilling to pay any part of the conversion cost.

2.0 ADAMS NATURAL GAS STATION DESIGN AND CONSTRUCTION

2.1 Background

An integral part of the demonstration project was to build and operate a natural gas fuelling station that would satisfy the needs of large commercial vehicles. While there were many public natural gas fuelling stations in the Greater Vancouver area, most of these were not on major trucking routes, were not easily accessible to large tractor-trailer combinations, and lacked sufficient natural gas storage and delivery capacity.

The John F. Adams & Son station (now Christie/Adams Distributors Limited), located at 3227 Norland Avenue in Burnaby, was already established as a multi-fuel (diesel, propane, and gasoline) cardlock fuel station in the heart of Greater Vancouver's trucking district. With ample land available for expansion, it was well situated to be developed as the first natural gas fuelling station specifically designed for the needs of the trucking industry.

Management of the Adams station had originally designed a CNG/gasoline station expansion for cars and light trucks. Under the terms of this demonstration project, the previous expansion plans for the CNG/gasoline station were modified to better meet the needs of large CNG/diesel trucks by:

- Enlarging the land area to be used;
- Increasing the fill, bedding and paving area;
- Upgrading the gas storage capacity and specifications to meet ASME standards;
- Increasing the 1" schedule 160 piping to 1 1/2" double extra heavy piping; butt weld fittings with 100% radiography testing;
- Re-sizing the compressor, CNG storage and electrical room, including foundations and piling to accommodate the five-year development plan for the CNG/diesel facility, in addition to the CNG/gasoline load requirement;
- Relocating a power pole at the eastern exit in order to provide sufficient turning radius for large trucks, and providing a second pole;

- Expanding the "Computrol" fuel sales monitoring computer from a 4-hose to an 8-hose unit, to serve the CNG diesel fuelling island;
- Changing design parameters to ensure acceptable fill time for large trucks.

Greg Cripps of B.C. Gas played an instrumental role in design of the Adams station. Construction of the station commenced in December, 1986 and was completed by March, 1987.

2.2 Adams Natural Gas Station Overview

The Adams (now Christie Adams) natural gas fuelling station, as shown in Figure 1 (page xiv), has been designed as a 24-hour, 7-day per week cardlock operation to service light and heavy duty commercial vehicles. The station has been designed to accommodate line-haul trucks and trailers, provide quick filling times, provide adequate storage and recharge capabilities, and easily accommodate increased load development. It also offers cardlock fuel facilities dispensing diesel, gasoline, and propane fuels.

The current system utilizes a 224 cfm Prescon compressor and 31,500 scf of ASME storage. A two-hose dispenser with Micro Motion meters is installed to satisfy the current demand of natural gas vehicles. The dispensers deliver cardlock controlled, self-serve, 3,000 psig, compressed natural gas in a fast-fill mode via a three ASME pressure vessel priority system with independent sequencing at each of the two outlets. A detailed description of the Adams fuel station design and specifications is provided in the next section.

2.3 Details of Fuelling Station Design and Equipment

2.3.1 Compressor

- Prescon model 3D360/6/100R, serial no. 4299, "W" shape, 3-stage, 3-cylinder, water-cooled, reciprocating, lubricated crosshead.

- Flow capacity 380 cubic metres per hour (224 cfm) at 60 psig inlet gas pressure and 3,600 psig discharge pressure.
- Inlet pressure range 25 psig minimum, 65 psig maximum.
- Maximum discharge pressure 4,000 psig.
- Maximum speed 760 rpm.

2.3.2 Storage Vessels

- 3 CP Industries ASME pressure vessels for natural gas storage.
- 20" nominal O.D., 22' nominal length.
- Volume: 35 cu. ft. per vessel, 105 cu. ft. total.
- Gas capacity: 10,500 scf per vessel, 31,500 scf total.
- Design pressure: 4,000 psi.
- Bottom drain valves with plugs on each vessel.
- Each vessel complete with 1" outlet valve and ASME pressure relief valve.
- Blind flanges are incorporated with the piping for future connection of additional vessels.
- Foundation, base and frame are designed to accommodate a future addition of six vessels, for a total of nine.

2.3.3 Priority Control Panel

This Prescon high-flow capacity priority control panel utilizes a three-bank cascade system with a compressor priority to maximize the short-term filling capacity of the whole system. It utilizes a flow management system to direct the compressor flow to where it is needed, when it is needed.

The order of priority of gas transfer is as follows:

(1) vehicle - compressor;
(2) Bank #3 - restore (high pressure bank);
(3) Bank #2 - restore (intermediate pressure bank);
(4) Bank #1 - restore (low pressure bank).

This policy assures that the compressor restores the higher pressure vessels first, or supplies gas directly to the vehicles when high bank is not able to top up to 3,000 psig.

Conversely, flow from the bank storage to the vehicles is transferred sequentially as follows:

(1) from Bank #1;
(2) from Bank #2;
(3) from Bank #3.

This implies that during high demand periods, Bank #1 may become depleted, but there will still be the filling capability from the higher pressure banks, or directly from the compressor, if necessary.

The long-term (average) filling capacity of a system depends mainly on the compressor output capacity. The short term (peak period) filling capacity of a system depends mainly on the storage capacity. However, under the guidelines above, the short term filling capacity of a three-bank system can effectively double that of a single-bank system.

2.3.4 Dispenser

- Prescon DAM-3 three line system, dual-hose transfer unit designed for rapid filling in multi-vehicle fuelling stations where the cascade sequence occurs independently at every dispenser. - Consumer & Corporate Affairs and CSA approved.
- Two Micro Motion meters, fill hoses, breakaways fittings, fill/purge valves and standard CGA B149.1 fuel probes.
- Temperature-compensated pressure regulation providing equivalent pressure of 3,000 psig at 70 degrees Fahrenheit and with a downstream relief to prevent pressure exceeding 3,450 psig.
- All meters, valves, fittings and tubing designed for a working pressure of 4,000 psig.
- Computerized dispensers shows selling price in dollars per kilogram, quantity sold in kilograms and total sale in dollars.

2.3.5 Dispenser Control Unit

- Computrol Fleet 600 pump control unit with receipt printer.
- Software to generate management reports.
- Permits unattended 24 hour operation via cardlock.
- All functions can be controlled at the fuelling site and/or remotely controlled over standard phone lines.

3.0 INITIATION OF DEMONSTRATION PROJECT

In May, 1988 a team consisting of the following individuals was assembled to initiate the demonstration project:

John Adams	John F. Adams & Son Ltd.
Michael Sinclair	Canadian Resourcecon Ltd.
Joe Haddon and Bill Hennessey	B.C. Gas Inc.

The overall goal of this team was to secure demonstration vehicles that would be converted to natural gas/diesel operation under the Adams project. In order to achieve this goal, however, the team first had to address a number of specific objectives:

1. Select a natural gas conversion system for the vehicles to be converted.

2. Secure the participation of a major local engine distributor to provide technical support and credibility to the demonstration.

3. Obtain the participation of B.C. Hydro Gas Division and Inland Natural Gas through the loan of equipment and provision of technical support.

4. Put in place an additional natural gas fuelling station at a key highway junction between Vancouver and Interior British Columbia locations.

5. Identify fleets that might be interested in participating in demonstration project.

6. Evaluate the suitability of such fleets.

7. Sign demonstration agreements with selected fleets.

3.1 Selection of Natural Gas/Diesel Conversion System

A number of different systems used to convert diesel engines to dual fuel natural gas/diesel operation were considered for use in the Adams demonstration project. The main selection criterion was that the system had to be proven, either by extensive dynamometer or road testing. Consideration was also given to the availability of local support and service personnel in the Vancouver area and reported thermal efficiency relative to operation on straight diesel.

In order to establish the reliability, relative fuel efficiency, and other operational parameters of various conversion systems, the team contacted suppliers of natural gas/diesel conversion systems throughout North America, as well as fleets with experience in using these systems. The chief difficulty in assessing the relative merits of alternative natural gas/diesel systems was a lack of good monitoring data to support performance claims.

After considerable research and deliberation, the team selected the conversion system developed by Cryogas Engineering Ltd. of Vancouver, B.C. The Cryogas system was chosen for a number of reasons:

- It had been developed for the popular Cummins 855 cubic inch family of engines, having been tested in both 350 and 400 HP models of this engine;

- Natural gas/diesel fuelling is controlled by a programmable microprocessor, providing certain advantages over mechanically-controlled first-generation conversion systems;

- It had undergone extensive dynamometer testing, as well as road testing;

- The company was based in Vancouver, enabling it to provide on-going support of the conversion system throughout the demonstration.

3.2 Participation of Local Engine Distributor

The survey of fleet operators in the vicinity of the Adams fuelling station indicated that they would be reluctant to have their vehicles converted without the sanction and support of the engine manufacturer or distributor. This reluctance resulted mainly from a concern about voiding their factory engine warranty if it were modified to natural gas operation, while there also were some reservations about the quality of on-going technical support from a company other than an authorized Cummins distributor.

It was therefore decided to seek the participation of the local Cummins distributor in the following areas:

- To act as prime contractor for the conversion, and oversee the conversion in its shop;

- To provide a backup warranty to the effect that conversion of the engine to dual fuel natural gas/diesel would not void or limit any of the warranties or coverages by the Cummins Engine Company.

- To provide ongoing maintenance, service, and technical support for the natural gas fuelling system at its network of shops throughout the province.

- To assist the team in identifying and attracting suitable demonstration participants from its existing customer base.

Fortunately, the management of Cummins British Columbia showed a keen interest in natural gas as an alternative fuel for heavy trucks and buses, to the extent that the project team was able to secure its participation to undertake these functions.

3.3 Participation of Local Natural Gas Utilities

B.C. Gas Inc., as noted earlier, has been a key sponsor of this demonstration project, both in its planning and execution. The utility was

instrumental in supporting the initial Enerdemo application, designing the Adams fuelling station, and providing technical support. B.C. Gas agreed to loan the required CNG storage cylinders for the demonstration, to a maximum of $18,000.

Similarly, Inland Natural Gas (now also B.C. Gas Inc.) was approached to participate in the demonstration through the provision of a natural gas fuelling station, as described in the following section.

3.4 Installation of Cache Creek Natural Gas Fuelling Station

The project team's demonstration plan called for at least one highway truck to operate between the Greater Vancouver area and the Interior of the province. While there were a number of existing natural gas stations in such Interior locations as Prince George, Quesnel, Williams Lake, Kamloops, Merritt, and Vernon, fuelling was not available at the key junction point of Cache Creek.

Inland Natural Gas, which provided natural service to this area of the province, was therefore approached at an early stage of the demonstration planning to seek its cooperation in installing a natural gas fuelling station at Cache Creek. Once a commitment from a fleet had been secured to convert one of its trucks operating between Vancouver and the Interior to natural gas/diesel operation, Inland agreed to install a fuelling facility at this location. A natural gas station was installed at the Cache Creek Texaco station during January 1989 under the direction of Roger Anastasiou of Inland Natural Gas.

Inland Natural Gas had, independently of this project, eventually intended to install a public fuelling station at Cache Creek to serve car and light truck traffic at this highway junction point. The required capacity for it was therefore relatively small. Technical specifications of the Cache Creek natural gas fuelling station are as follows:

Technical Specifications of Cache Creek Fuelling Station

Compression

Manufacturer	LMF (Austria)
Model	V16
Capacity	30 - 35 scfm
Power	30 HP
Packaging	CNG Fuel Systems

Gas Storage

Storage volume	2500 litres water capacity (500 kgs natural gas)
Number of vessels	50
Type of vessel	CTC/DOT 3AA 3600 psi
Manufacturer	TI Chesterfield (U.K.)
Arrangement	2 bank with electronic automatic sequencing

Dispensing

Manufacturer	CNG Fuel Systems
Model	1001
Type	Single hose electronic

The station is portable with a maximum capacity of 200,000 litres gasoline equivalent per year. With normal light vehicle traffic, it can supply up to 40 fills per day at 20 kg per fill. The demonstration truck that fuels at this station takes up to 100 kg per fill and is therefore equivalent to five normal vehicles arriving simultaneously. Although the station is quite capable of providing delivery for this circumstance, additional large vehicles on this route would necessitate additional compression and dispensing capacity.

There were three special design criteria which were required when the demonstration truck was added to the requirements of this station:

1 **Compression:** The daily compression capacity had to be adequate for the additional load.

2. **Storage:** The storage had to be large enough to transfer 100 kgs to the truck. Because of the small capacity of the compressor, all 100 kgs had to be generated from storage, with no help from the compressor. To achieve this, 50 cylinders were installed - more than normal for typical CNG stations. The size of the "high bank" was limited to 10 cylinders to ensure that the compressor could recover full delivery pressure quickly after a fill.

   In addition, the storage was separated into only two banks instead of three. This was done to avoid the flow-restricting sequencing equipment required with three bank systems (sequencing systems are also typically high in maintenance which is not desirable in a remote location such as Cache Creek).

3. **Dispensing:** The biggest challenge with this unit was to provide a reasonably quick fill of a large volume. A variety of changes were made to the piping system between the storage and dispenser as well as the dispenser itself. 1/4 inch tubing was replaced with 1/2 and 3/8 tubing throughout. Additionally, the componentry in the dispenser was rearranged to provide faster flows.

3.5 Identification and Evaluation of Participating Fleets

By virtue of its role as the local distributor of Cummins engines, Cummins British Columbia was well-positioned to identify fleets that would be appropriate to participate in this demonstration. In evaluating fleets and vehicles, the following criteria were considered:

Operational factors:

- ability to fuel at the Adams station on regular basis;
- moderately high fuel consumption per vehicle;
- existence of control vehicles on similar duty cycle.

Technical factors:

- engines for which Cryogas conversion system is appropriate;
- engines in good mechanical condition;
- sufficient space to accommodate cylinders on vehicle.

Economic factors:

- vehicle kept long enough to yield payback on conversion cost;
- high enough diesel price to yield substantial fuel cost savings.

Management factors:

- strong commitment to making demonstration program work;
- demonstrated record-keeping ability to provide meaningful monitoring data;
- dedication to a proven truck fleet maintenance program.

Taking into consideration the foregoing criteria, Canada Safeway Ltd. was identified as a good candidate for a participating fleet. The Burnaby truck department of Canada Safeway was approached and, after some discussion, the company signed an agreement to participate in August 1988.

4.0 CONVERSION OF SAFEWAY TRUCK

4.1 Description of Demonstration Vehicle

A 1984 Freightliner cabover tractor (Unit B121) engined with a Cummins Big Cam III 350 HP (1900 RPM) was selected as the demonstration vehicle from Safeway's fleet. This 166-inch wheelbase, tandem axle tractor is equipped with a 15-speed Roadranger transmission (RT 14615, high gear direct drive) and has a 3.73:1 rear axle ratio. Tires on the truck are 11 x 24.5 inch radials turning 476 revolutions per mile. This truck hauls trailers of up to 53 feet in length, and has a registered gross vehicle weight of up to 47,000 kg.

The truck typically runs twice a week from Safeway's Burnaby warehouse to one or more Interior locations (most often turning around at Prince George), then returns to the yard the next day. The truck is assigned to local hauls in the Fraser Valley two days per week, in between round trips to the Interior of British Columbia. The truck is usually idle on Sundays. Most of the time the truck is assigned to two drivers, one highway and one local, although there are occasional relief drivers

4.2 Conversion Planning

Given the findings of the market research report, as summarized in Section 1.2 of this report, the project team would have preferred to convert a 444 HP version of the Cummins block. However, Cryogas Engineering was of the opinion that additional development work would be required before they would be willing to convert an operational vehicle of this type. The decision was therefore taken to convert a lower horsepower unit, since the previous experience of Cryogas with 855 Cummins engines had been restricted to engines in the 350 to 400 HP range.

Rather than convert the existing Big Cam III engine in the truck to natural gas/diesel operation, it was decided to replace it with a factory-reconditioned 350 HP (2100 RPM) Big Cam IV engine. This decision was taken for several reasons:

1. The existing engine was almost due for a rebuild, and it would have been unwise to convert an engine in less than top condition.

2. The Big Cam IV model is the most current of Cummins 855 cubic inch series of diesel truck engines, so it was considered more logical to convert this model rather than an older one.

3. The Big Cam IV incorporates a "low-flow" cooling system for the charge air; this system offers the possibility of simpler modifications than would otherwise be required in order to reduce the charge air temperature to a level needed to minimize the potential for detonation.

For these reasons the original Big Cam III engine in the truck was replaced with a factory-reconditioned Big Cam IV NTC-350 HP model during February of 1989. The truck was broken in on straight diesel for about 9,000 km prior to conversion to natural gas fuelling.

A low-flow radiator was installed along with the rebuilt engine. During conversion to natural gas fuelling, Cryogas made a number of modifications to the factory cooling system to control intercooler temperature more closely and provide cooler charge air.

A key element in planning of the conversion was the quantity and configuration of natural gas storage to be carried on the demonstration tractor. It was decided that the quantity of gas should be sufficient to allow the truck to travel from Burnaby to Cache Creek without running out of natural gas, a distance of about 335 kilometres - the longest run between natural gas fuelling stations on the truck's various routes. Natural gas storage requirements were estimated on the basis of the following parameters:

- 6 mpg (2.12 km/litre) diesel fuel equivalent;
- 1.34 litres of diesel per kilogram of natural gas at equal fuel efficiency;
- about 10 percent loss in fuel efficiency relative to straight diesel;
- 0.166 kilograms of natural gas per litre of water capacity;

- as much as 70 percent diesel replacement by natural gas.

Based upon these parameters, it was decided to install about 600 litres water capacity of natural gas storage. Careful measurement of the truck was undertaken to establish the maximum dimensions and placement of the storage cylinders to be installed. Ultimately, four 94-litre Alcoa composite-reinforced aluminum cylinders were installed in place of the 120 Imperial gallon (567 litre) diesel tank on the right side of the truck, and two 118-litre Alcoa tanks were installed crossways behind the cab, for a total of 612 litres water capacity storage. The layout of the natural gas storage cylinders may be seen in Figure 2 (page xiv) which shows Safeway Unit B121 following conversion to natural gas/diesel operation.

Joe Haddon of B.C. Gas Inc. designed the natural gas storage system for the truck. A special feature of this storage system design is the incorporation of two fuelling blocks on each side of the truck, connected to the cylinders by 3/8 and 1/2-inch lines in an attempt to make fuelling more convenient and faster.

Cylinder mounting frames and brackets have been designed to withstand 20 g horizontal forces and 8 g vertical forces. On a net basis, the natural gas storage tanks, frame and brackets weighed only 608.5 lbs. more than the diesel fuel and tank which they replaced. In fact, it was subsequently determined that the additional weight did not reduce the payload capacity of the tractor-trailer combination, given the light weight of the rear axles and suspension on this particular truck configuration. A detailed breakdown of the individual weights of diesel equipment removed and natural gas equipment added is provided in Table 4-1 on page 21.

4.3 Conversion of Safeway Truck to Natural Gas Fuelling

Conversion of Safeway Truck B121 to natural gas/diesel operation was carried out by John McKinnon and Jim White of Cryogas Engineering. The Cryogas natural gas/diesel fuel control system employs an on-board microprocessor based on the Motorola 68HC11 chip. It senses engine RPM and fuel pressure to control diesel injection and gas flow through a gas

admission valve into the turbocharger intake. Other components of the system include:

- a diesel fuel control manifold, interconnected with the engine fuel pump and injection rail. The manifold reduces diesel flow when operating on dual fuel and also provides the basic engine control signal to the controller;
- auxiliary water pump, low flow radiator, and two thermostats to control intake air manifold temperature and engine operating water temperature;
- high pressure gas regulator (3000 to 60 psi), gas pre-heater, and low pressure regulator (60 to 3.5 psi).

A laptop PC is used to reprogram the on-board computer. The conversion system was engineered to closely match the engine performance, operating and exhaust temperatures of the original diesel engine.

Natural gas storage cylinders, prefabricated brackets, engine conversion components and a variety of miscellaneous fittings were assembled prior to the truck entering the Cummins shop in Burnaby, where the conversion was undertaken.

The truck entered the shop on February 21 and the converted truck left the shop for its first fill of natural gas on March 4, 1989. Testing, modification and fine tuning of the conversion and storage systems were carried out before the truck went into regular service on March 15. A detailed account of the progress of the initial conversion and subsequent modifications, adjustments, and repairs is provided in Appendix B.

TABLE 4-1: NATURAL GAS CONVERSION FUEL STORAGE WEIGHT CHANGE ON SAFEWAY TRUCK B121

Natural Gas Equipment Added	Pounds
Cylinders:	
4 x 94 litres water capacity (4 x 162 lbs)	648.0
2 x 118 litres water capacity (2 x 193 lbs)	386.0
Mounting frame brackets & material	285.0
Cylinder hanger kits 6 x 28 lbs	168.0
Natural gas fuel: 612 L cap. x 1 kg NG/6 L cap. x 2.2 lb/kg	224.0
Flat deck braces 1/2" x 3" x 84"	35.5
Misc. equipment (tubing, cylinder, fuelling blocks, shut-off valve, plates, bolts, cylinder covers, brackets, fittings, gauges)	50.0
Total	1,796.5

Diesel Equipment Removed	
Diesel fuel tank from right side	94.0
Tank hangers & straps 23 lbs x 2	46.0
Diesel fuel 567 litres, summer fuel .84 kg/L	1,048.0
Total	1,188.0

Net Weight Added To Truck	1,796.5 lb - 1,188 lb =	608.5

- Right side weight balance

Cylinders: 4 x 162 lbs	648.0
Brackets: 2/3 x 538.5 lb	359.0
Gas: 376 L cap. x 1 kg NG/6 L cap. x 2.2 lb/kg	138.0
Total Added	1,145.0
Removed full diesel tank and hangers	1,188.0
Net right side weight reduction	43.0

- Added weight on deck 1.796.5 lb - 1,145 lb = 651.5

Basically the four 94 L cylinders, hangers, and gas on the right side are equivalent to the full diesel tank which was removed. The net weight added to the truck consists of the two 118 L cylinders, hangers and gas which is about 610 lbs.

5.0 MONITORING OF SAFEWAY TRUCK

5.1 Monitoring Procedures

As indicated earlier in this report, obtaining consistent and good quality data has been a major problem for other vehicles converted to natural gas fuelling. Monitoring of a vehicle operating on two fuels is particularly challenging, as the odometer readings at which the vehicle is switched over from dual fuel natural gas/diesel to straight diesel operation must be recorded, along with fuel consumption and other data.

Fortunately, Canada Safeway already had in place an excellent fleet fuel management system for which the drivers were accustomed to filling out fuel cards. The existing fuel cards were modified to include the following:

- the quantity of natural gas filled, as well as diesel fuel;
- fuel switches from gas/diesel to diesel (or vice versa) and the odometer reading at which these occurred;
- the Gross Vehicle Weight of the truck, if available, and the location and odometer reading at which it was taken.

A sample copy of the fuel card used for this project is shown on the following page.

The Safeway truck presented some challenges to monitoring, as it does not operate on a fixed route, while it has several different drivers. Typically, it operates one day making local hauls in the Greater Vancouver/Fraser Valley area, then goes to the Interior on a two-day return trip. This pattern is repeated twice a week, with the truck idle the remaining one day per week.

It was originally intended that the local driver would fuel the truck with both diesel and natural gas at the Adams station at the beginning of his day, and again at the end of the day. This would have minimized the number of refuelling stops by the highway driver who, on a typical trip to the Interior, would fuel with natural gas at Cache Creek, then Quesnel,

before arriving at Prince George late in the evening. In practice, however, the highway driver often had to fuel at the Adams station at the beginning of his trip, as well as at the Interior stations.

Aside from monitoring fuel consumption, a number of other parameters were also monitored, including:

- oil analyses at regular intervals;
- relative fuelling times for natural gas and diesel at various fuelling stations;
- relative natural gas and diesel fuel costs;
- driver and maintenance staff feedback.

A concise set of data collection instructions for the drivers was provided on a two-sided plasticized card, along with instructions for natural gas fuelling procedures and operating the Cryogas natural gas/diesel system. A copy of this set of instructions, which is kept in the truck cab at all times, is shown in Appendix C.

Drivers and maintenance staff were briefed on the operation of the natural gas system at the beginning of the demonstration. They were also shown a video demonstrating the safety of natural gas fuel cylinders undergoing a variety of torture tests (dropped from a crane, directly exposed to fire, being shot with incendiary bullets, etc.).

5.2 Monitoring Data

The statistical data gathered were entered into a spreadsheet, included in Appendix D of this report. From the input monitoring data, the following parameters were calculated:

- cumulative and trip-by-trip fuel use, percentage natural gas use, and fuel efficiency (km/litre of diesel fuel equivalent, relative Lower Heating Value basis);

- cumulative distance travelled, versus distance on straight diesel

- distance between odometer readings at which the truck was fuelled, or switched to diesel or natural gas;

The latter information proved to be invaluable, as the apparent distance between fuelling points at one stage in the monitoring (517,261 km) was abruptly reduced by about 16 percent, alerting the monitoring team to an inadvertent maladjustment of the odometer during a visit to the Safeway maintenance shop for re-calibration of the tachometer. Distances between odometer readings for the interval from 517,261 to 521,060 kilometres, when the odometer was correctly re-calibrated, have therefore been adjusted upward by about 16 percent.

Natural gas consumption, measured in kilograms, was converted into litres of diesel equivalent based upon the relative lower heating values of the two fuels. Appendix E details the method of calculating the equivalency factor between kilograms of natural gas and litres of diesel fuel, and provides specifications for the natural gas and diesel fuel consumed by the Safeway truck during the period of the demonstration. Based upon the analysis in Appendix E, one kilogram of natural gas should have equated to 1.34 litres of diesel fuel on average during the monitoring period, given equal thermal efficiency with both fuels. In subsequent discussion, natural gas consumption is expressed in terms of litres of diesel equivalent, abbreviated to "lde".

Key monitoring results are summarized in Table 5-1 on a quarterly basis and are discussed in detail in the following section.

5.2.1 Distance travelled

Monitoring of fuel consumption by the Safeway truck began on April 6, 1989, with 512,591 kilometres on the odometer. During the first quarter, from April 6 to July 12, 1989, the truck experienced a very high utilization rate, accumulating 25,713 km, or an average of 1,837 km week. In the second quarter, from July 12 to October 5, 1989, the Safeway tractor logged 16,074 km, or 1,340 km per week - a 27 percent reduction from the

first quarter. The considerable reduction in utilization of the tractor resulted from several factors, including the use of the truck in promotional activities and a number of minor operational problems with the natural gas fuel system on the truck. These factors are discussed in more detail in subsequent sections of the report.

A further reduction in distance travelled by the tractor occurred during the third quarter of the demonstration (October 5 to December 22, 1989) when it dropped to 10,313 km, or 936 km per week. The truck was confined primarily to local hauls during the third quarter, as it made only three trips to the Interior. This trend continued during the fourth quarter (December 22, 1989 to April 4, 1990), as the weekly average dropped to less than 800 km. The truck, however, did experience more highway use during the fourth quarter, as it made 7 trips to the Interior.

While the reduced utilization of the truck during this time period may be attributed to a variety of factors, a disabling injury suffered by the key Cryogas employee responsible for on-going maintenance of the natural gas/diesel conversion system was probably the major factor. As a result of this injury which occurred towards the end of the second quarter (but was unrelated to this particular project), there was a loss of continuity in the maintenance of the system. Other factors contributing to the reduced utilization of the tractor include driver vacation days off and operational problems, many of which were totally unrelated to the natural gas/diesel conversion system.

In total, the truck logged just over 64,000 km over the one-year demonstration period. If it had been fully utilized, it normally would have travelled about 100,000 km on the same routes during the course of a year.

5.2.2 Operating Range

With an original diesel fuel storage capacity of more than 1000 litres, the truck had a range on straight diesel of well over 2000 km. On natural gas operation, this was typically reduced to less than 350 km when the truck was loaded and hauling up-highway to the Interior. On one trip, however,

(October 17 - 18, 1989) the truck travelled 451 km from Cache Creek to Prince George (uphill and loaded) without switching to straight diesel. Returning from Prince George to Kamloops on the same trip, running downhill and empty, the truck ran 535 km on a single fill of natural gas, again a record distance for the demonstration period. The range on natural gas/diesel operation to some extent depends on the driver's tolerance to reduced power as the gas storage pressure decreases. In any event, the truck has sufficient diesel storage to travel another 1,000 km on straight diesel on highway runs after it runs out of natural gas.

5.2.3 Relative Fuel Efficiency

Without the existence of an identical control vehicle, relative fuel efficiency had to be calculated by operating the demonstration truck on straight diesel from time to time, and comparing its relative fuel consumption to that on dual fuel natural gas/diesel operation. The best comparative fuel efficiency data were obtained during the first and second quarters, during which time the truck was used mainly on runs to the Interior and had a high utilization factor.

The calculation of relative fuel efficiency on dual fuel versus straight diesel requires strict operating procedures and good record-keeping by the drivers. For example, if the truck is switched from natural gas to diesel between fills, the relative amounts of diesel consumed in the single versus dual fuel modes must be estimated. Similarly, the truck needs to be topped up with both fuels at the same location to permit meaningful calculation of dual fuel efficiency. Finally, the drivers must not only record the amounts of fuel taken on, along with the associated odometer reading at the time of refuelling, and but also the odometer reading at the time of switching from one fuel to another.

A number of fuel switches were not recorded, particularly during the fourth quarter. This was apparent from large variations in the ratio of natural gas to diesel, or in the km/litre fuel efficiency measure. A model, incorporating observed relationships in the ratio of gas to diesel and km/litre on dual fuel versus straight diesel was developed to estimate the

odometer reading at which unknown fuel switches occurred. Based upon the very consistent relationships in these parameters, it was possible to estimate the points at which such fuel switches occurred with a fair degree of confidence. Similarly, a few refuellings went unreported, but these were eventually identified through Computrol records.

Another problematic area of fuel monitoring was the frequent practice of not topping up with both fuels at the same location. This practice, combined with frequent switching between the dual fuel and monofuel modes, resulted in the availability of only a limited amount of fuel efficiency data on a trip-by-trip basis.

The engine in the truck was broken in on straight diesel during February, 1989. During the 6,219 km break-in period, fuel consumption was high, averaging only 1.85 km/litre (5.24 mpg) versus 2.12 km/litre (6.02 mpg) during the lifetime of its predecessor Big Cam III, 350 HP engine. This poor fuel efficiency may have resulted from the prevailing cold weather and the use of low-pour winter diesel fuel, as well as initial tightness in the newly-rebuilt engine.

First Quarter Fuel Efficiency

Operation on natural gas/diesel dual fuel during the three-month period from April to July 12 1989, resulted in an overall average fuel consumption of 1.70 km/lde, or 4.80 mpg, diesel fuel equivalent basis. This compares with an average fuel efficiency of 2.18 km/l (6.16 mpg) on straight diesel recorded over a total distance of 5700 km during the period. Thus, about 28 percent more energy per kilometre was consumed in the dual fuel mode than in the single fuel diesel mode.

However, for the purposes of calculating comparative fuel efficiency, the overall three-month average on natural gas/diesel is not considered representative for several reasons:

1. It includes 15,000 km operation during April and May, whereas diesel operation occurred primarily during June and July.

2. The runs on straight diesel consisted almost exclusively of highway operation, whereas the dual fuel operation included more urban runs where the fuel efficiency was much lower.

It is therefore more appropriate to compare the foregoing diesel fuel efficiency with dual fuel efficiency on highway operation during the same time period. Dual fuel consumption over the course of two trips to the Interior during June (between the two test periods on straight diesel) averaged about 1.85 km/lde (5.23 mpg) over a total distance of 3250 km. The installation of the hotter thermostats during the last week of May (528,505 km) does not seem to have significantly improved fuel efficiency, as two trips to Prince George during May equalled or surpassed the foregoing level.

The 1.85 km/lde (5.23 mpg) level has been adopted for dual fuel operation, as the truck has delivered several highway runs at least equal to this level before and after the test runs on straight diesel. Given the foregoing fuel use coefficients for highway use (2.18 km/l for monofuel diesel, 1.85 km/lde for natural gas/diesel), it is calculated that natural gas/diesel operation results in a 15 percent loss in thermal efficiency relative to straight diesel operation, as discussed in detail in Appendix E.

Second Quarter Fuel Efficiency

As indicated in Table 5-1, dual and single fuel efficiencies during the second quarter were virtually the same as those observed during the first quarter. The ratio of dual fuel versus single fuel use per kilometre therefore also remained constant at more than 1.28 times. Overall fuel efficiency increased somewhat, from 1.80 km/lde during the first quarter, to 1.85 km/lde during the second. This resulted from a greater proportion of the distance being travelled on straight diesel operation.

Only limited trip-by-trip data for duel fuel natural gas/diesel versus straight diesel were available during the second quarter. This resulted from frequent fuel switching between fuel fills, making precise calculation of gas

versus diesel fuel efficiency impossible in such cases. The fuel efficiency data that were available from this quarter, however, were not inconsistent with data from the previous quarter.

More specifically, on a return trip to Vernon and back that began on July 28, the total natural gas/diesel fuel efficiency was equivalent to 1.82 km/lde. On a subsequent run to Prince George and back (August 15), the corresponding figure was 1.87 km/lde. The lower efficiency experienced during the July 28th trip may be attributable to the truck going over the Coquihalla Highway where there is a greater elevation gain than on the Fraser Canyon route to Prince George. In any case, these figures are not out of line with the 1.85 km/lde figure calculated to represent highway operation of the truck on dual fuel natural gas/diesel during the first quarter.

On a local run (July 18), fuel efficiency on dual fuel operation was 1.41 km/lde, again consistent with first quarter results for around-town operation.

On two highway trips back from the Interior on straight diesel, fuel efficiency was 2.12. and 2.58 km/litre. These figures are not considered representative of overall diesel fuel efficiency, however, since the truck was empty and going downhill in both cases.

In an attempt to provide better comparative fuel use data for the remainder of the project, one-week periods each month were scheduled in advance during which the truck was operate on straight diesel. Drivers were requested to top up with both fuels to a consistent level after each run. In this manner it was hoped that more consistent comparisons of natural gas versus diesel fuel efficiency could be made for both local and highway duty cycles. Unfortunately, for a variety of reasons, this effort met with only limited success.

Third Quarter Fuel Efficiency

With the increased use of the truck for local hauls during the third quarter, the dual fuel efficiency dropped off substantially, to 1.60 km/lde, compared to about 1.70 km/lde during the first two quarters. Weighted averaged fuel efficiency on straight diesel also fell off sharply, to about 2.03 km/litre versus 2.17 km/litre during the first two quarters. Reduction in diesel fuel efficiency may be partially due to the truck using Interior winter grade diesel for the majority of its diesel requirements during this time period. The ratio of dual fuel to single fuel use per kilometre remained almost constant, at about 1.27 times. Again, however, a substantial proportion of diesel operation during the quarter was on highway runs, whereas dual fuel operation was largely restricted to local routes.

Fourth Quarter Fuel Efficiency

Fuel efficiency data during this quarter is considered to be somewhat less reliable than the preceding three quarters, as it was necessary to estimate the point at which fuel switches occurred on 8 occasions. Nevertheless, the data are not unreasonable, taking into account operational conditions during this quarter. More specifically, with the increased use of the truck on highway runs, dual fuel efficiency increased to 1.64 km/lde, versus 1.60 km/lde during the 3rd quarter, and about 1.70 km/lde during the first two quarters. Straight diesel fuel efficiency fell off to 1.99 km/litre, versus 2.03 km/litre during the previous quarter. This may be a result of the increased use of straight diesel for local runs during the quarter. In any event, the ratio of dual fuel to single fuel energy use per kilometre was reduced to about 1.21 times. Overall fuel efficiency during the fourth quarter was reduced to 1.75 km/lde.

Overall Fuel Efficiency

Table 5-1 shows that total fuel use per km remained fairly consistent over the monitoring period, averaging about 1.80 km/litre of diesel fuel equivalent. Dual fuel use averaged 1.67 km/lde versus 2.10 km/lde for

straight diesel, which means that the dual fuel mode consumed almost 26 percent more fuel per kilometre on average. Again, it should be emphasized that much more of the straight diesel operation occurred on highway runs than did dual fuel operation. This comparison therefore is not a fair one.

Only limited trip-by-trip fuel efficiency data for local runs are available. Local runs are quite variable in terms of their duty cycle. On some local trips the truck runs out to Chilliwack, which is a flat, steady freeway haul on which excellent fuel economy is attainable. On other local trips the truck travels in stop-and-go local traffic to various urban locations such as North and West Vancouver, resulting in considerably reduced fuel economy. It is difficult to find data for two identical local runs on natural gas/diesel versus straight diesel for the purposes of comparing fuel efficiency. Topping up to consistent levels when refuelling is also a greater source of potential error on the shorter local hauls.

Most of the local hauls for which trip-by-trip fuel efficiency data on dual fuel operation are available were made during the first quarter between April 17 and June 22. During this period the tractor averaged 1.58 km/lde over 1632 km of local hauls, as detailed in Table E-3 of Appendix E. Most of the local hauls for which trip-by-trip diesel fuel efficiency data are available, on the other hand, occurred in the third quarter, between November 16 and December 12. Over 1840 km of local operation the truck averaged 1.94 km/l. Thus, dual fuel operation apparently consumed about 23 percent more fuel per unit of distance than on straight diesel. However, most of the diesel consumed during the third quarter was Interior winter grade diesel which has significantly less heating value than the summer diesel used during the first quarter. Adjusting for this factor, it is estimated that dual fuel operation consumes about 25 percent more energy per unit of distance than straight diesel operation. This equates to a 20 percent loss in thermal efficiency. For the reasons noted earlier, along with the fact that the weather was somewhat colder during the third quarter than in the first quarter, this figure should be regarded as approximate rather than definitive.

By contrast, the comparative fuel efficiency data for highway operation, as experienced during the first two quarters, are considered to be much more reliable given their consistency over routes which were exactly comparable. As calculated in Table E-2 of Appendix E, dual fuel operation on the highway resulted in a 15 percent loss in thermal efficiency relative to straight diesel operation. This figure has been adopted for the purpose of examining the economics of the Cryogas system, given that the Cummins 855 engine family is primarily designed for highway operation.

5.2.4 Percentage of Natural Gas Used

By deducting the distances during which the truck was operated on straight diesel, along with associated quantities of diesel consumption (estimated on the basis of quarterly average trip-by-trip diesel fuel efficiency), the relative shares of natural gas versus diesel use were calculated. Overall, natural gas has provided a fairly consistent 59 to 60 percent of the total fuel use during dual fuel operation. This does not, however, mean that 60 percent of the diesel fuel that would have otherwise been consumed on straight diesel operation was replaced by natural gas, given the increase in total fuel consumption when operating in the dual fuel mode. Instead, the level of replacement is about 50 percent, calculated on the basis of the relative quantities of diesel consumed per kilometre during the two modes of operation. Based upon the information shown in Table 5-2, about 0.54 kg of natural gas and 0.48 litres of diesel are required to provide equal range to one litre of diesel.

On local runs natural gas use averaged a slightly lower proportion of total fuel consumption, amounting to about 58 percent during 1632 km of local operation during the first quarter.

5.2.5 Impact of Payload and Gradient on Fuel Consumption

The Safeway truck typically runs to Prince George fully loaded and returns with minimal loads of various product containers. In addition, on the way up to Prince George there is an elevation gain of about 1900 feet (579 metres). Reflecting these factors, natural gas consumption on the way up

to Prince George is typically 35 to 40 percent higher than on the return trip on an overall basis.

Dual fuel diesel fuel use, on the other hand, does not appear to vary nearly as much as natural gas does in this respect. On a trip to Prince George which started on March 21, 1990, fuel consumption per kilometre was only 7 percent more going up to Prince George than coming back. Thus it would appear that natural gas must constitute a much higher proportion of total fuel use under heavy engine loading, given the relative consistency of diesel fuel use. Unfortunately, since the truck was usually only topped up with diesel after each round trip to the Interior, fuel consumption data are not available to allow a precise calculation to be made.

Similarly, on straight diesel fuel there is much less variation in fuel use to and from the Interior. On the two trips to Prince George for which data are available, diesel consumption averaged about 13 percent more than on the return trip.

5.3 Maintenance Experience

Appendix B provides a detailed account of the maintenance experience of Safeway Unit B121 during the demonstration period. The following paragraphs summarize the major operational and maintenance considerations during this time period, other than those already discussed in Section 5.3.1.

5.3.1 Microprocessor Operation

The on-board microprocessor controlling natural gas and diesel fuelling generally functioned well during the demonstration. During the third quarter, however, the engine speed inexplicably climbed right up to the governor on several occasions. This intermittent problem was eventually traced to a faulty solder joint on one of the circuit boards in the microprocessor. Since this joint was repaired in January, the problem has not re-occurred.

5.3.2 Overheating

On several occasions drivers reporting that the truck was overheating, in some cases causing the warning buzzer to come on. The Murphy temperature switch gauge was found to be set too low, causing the engine to cut out at 210 degrees F. This was reset to 220 degrees F, which is the normal setting for other trucks in the fleet. After further complaints of overheating, it was decided to rationalize operation of the cooling system so that the shutters would open before the fan began operation at 195 degrees F. This modification appears to have lowered engine temperature to the same level as the rest of the fleet.

5.3.3 Electrical Problems

Several times during the second quarter, the truck experienced intermittent problems, with the truck engine stopping completely in some cases. This was ultimately traced to an intermittent short in a relay unrelated to the natural gas conversion system. This short, however, caused a low voltage condition in the electrical system which resulted in the fuel solenoid closing and not allowing fuel to the diesel fuel pump. In one case this caused a backfire in the exhaust system when diesel flow was interrupted.

Similarly, on another occasion, problems with the fuelling system began shortly after the starter in the truck was changed. Upon investigation it was found that a ground wire for the microprocessor, which was originally connected to a starter mounting screw, had been connected to a terminal on the starter relay. After this was corrected, the natural gas fuelling system again functioned properly.

5.3.4 High Pressure Regulator Wear

The high pressure MECO regulator originally used in the system has a seal block with 4 rotatable wear surfaces. On average, the seal block needs to be rotated to a new wear surface every month. On several occasions the relief valve downstream from the high pressure regulator was observed to be

leaking as a result of gas bypassing the regulator. Upon inspection the mating orifice seat for the seal block was found to be worn.

On April 16, 1990 the MECO regulator was replaced with an Impco HPR-501 unit to see if it would provide longer intervals between maintenance. To date (May 31, 1990), there have been no problems with the Impco regulator - in fact, it is maintaining more consistent outlet pressures than its predecessor.

5.3.5 Natural Gas Dispenser Problems

During July 1989, problems were encountered with the natural gas dispenser at the Christie/Adams station cutting out when two refuelling probes were used. The dispensers would shut off when cylinder pressures were between 700 and 1000 psi. The dispensers were then re-started and the cylinders were filled to capacity. Natural gas quality data from B.C. Gas indicated that the moisture content had increased significantly during July, possibly creating a freezing problem downstream from the fill blocks in the natural gas piping on the truck.

In order to address this problem, higher-flow check valves were installed in the two refuelling blocks on the right side of the truck. Since this modification, no further problems have been encountered with the natural gas dispenser cutting out before natural gas storage tanks were filled to capacity.

5.3.6 Oil Analyses

Analyses of the engine oil were carried out after each of the four oil changes during the demonstration. A printout of the wear analysis reports, included at the end of Appendix B, indicates normal dirt and metal wear rates. While a high soot content is shown on the March 12, 1990 sample, Safeway's maintenance manager indicates that there apparently is a problem in the oil analysis lab equipment that results in erroneously high soot readings for most of their trucks. Thus, based on oil analysis results to date, the converted engine appears to be holding up well. Given these oil

analysis results and the relatively low distance logged by the Safeway truck since its conversion (64,000 km to the beginning of April 1990), Safeway's fleet management has no plans to tear the engine down for inspection in immediate future.

5.4 Assessment of Operation and Maintenance of Safeway Truck

Liaison was maintained with Safeway truck drivers, maintenance and fleet management personnel throughout the project in order to obtain ongoing feedback concerning the operation of the truck and to address any problems that arose. At the end of the one-year monitoring period, Safeway personnel involved in the project were interviewed to establish their assessment of the viability of the natural gas conversion and fuelling systems demonstrated during this project.

5.4.1 Driver Impressions

Ultimately, drivers are in the best position to judge whether an alternative fuel system is operationally viable. Drivers of the demonstration truck were therefore asked to provide their assessment of the operation of the truck on natural gas/diesel versus straight diesel. They completed a brief questionnaire (see Table 5-3) and also provided subjective comments. From the questionnaire responses, it is apparent that there is quite a range of opinion as to the relative merits of the truck when on dual fuel versus straight diesel.

The major limitations of the system identified by the drivers were as follows:

1. Increased fuelling time;
2. Reduced range;
3. Loss of power at low gas storage pressures;
4. Accelerator response problems when shifting.

These factors, along with measures that were taken to correct them, are discussed in more detail in the following section.

1. **Increased fuelling time is a considerable inconvenience.** This is a more of a problem for the highway driver who may be required to fuel the truck three times each way going to and from the Interior. Prior to conversion the truck would fuel up with diesel only once every round trip to Prince George and back. Filling time for the tank and one-half of diesel fuel consumed (about 700 litres) in the past would usually take less than 15 minutes. By comparison, a round-trip on natural gas diesel requires 5 fuelling stops, 4 for natural gas and one for both natural gas and diesel. The Interior CNG stations at Cache Creek and Quesnel require an average of about 25 minutes per fill and, on occasion, have taken up to 35 minutes. By comparison, the Adams station typically takes about 20 minutes to fill up with both natural gas and diesel. In total then, the fill time for a round-trip on natural gas/diesel would take at least 2 hours versus only 15 minutes for straight diesel.

   This comparison does not take into account any waiting time in line-ups at the natural gas pumps, or the time it takes the truck to travel to the Adams station from the Safeway yard. These additional delays, however, would not occur in a commercial fleet natural gas station located in the trucking company's own yard.

   Thus, there is a very substantial increase in refuelling time for which Safeway has to compensate the drivers at the rate of almost $20/hr. Aside from the monetary cost of increased refuelling time, it lengthens an already-long trip (15 hours) to the Interior for the highway driver, resulting in substantially increased driver fatigue. The original highway driver asked to be transferred to another truck mainly because of the increased fuelling time. He was replaced by another driver who also found this to be a significant inconvenience. One partial solution to this problem is to have the truck already fuelled up prior to the highway driver starting his trip.

   In an attempt to reduce fuelling times, B.C. Gas installed two 3/8 inch diameter hoses at Cache Creek in place of the single 1/4 inch hose. This change has apparently reduced fuelling times somewhat, depending

upon the storage pressure at the station at any given time. On February 9, 1990, for example, the truck took on almost 99 kg at Cache Creek in about 20 minutes. On the following day, however, the fuelling time increased to 35 minutes for a fill of 105 kg. As a second step in reducing fill times at this station, B.C. Gas replaced two restrictive hose valves with ones having larger orifices. This modification, however, appears not to have reduced fuelling times significantly.

During July, 1989 a problem with icing of the fill receptacles developed at the Adams station, slowing the fill process. This problem appears to be linked to a corresponding increase in the water content of natural gas in the B.C. Gas system and restrictions in the refuelling receptacle. Fill probe receptacles with larger check valve orifices installed on the Safeway truck during July appear to have resolved this problem, while reducing fill times somewhat.

2. **Reduced range.** The problem of increased fuelling time in large part relates to the fact that the truck can travel for limited distances on natural gas/diesel between natural gas refuellings, as discussed earlier. Only a portion of the time spent during refuelling stops is related to actual fuelling. Thus, if the truck had greater storage capacity, some savings in fuelling time could be achieved. These savings, of course would have to be weighed against the additional cost of more storage capacity, along with any reduction in payload capacity resulting from the added weight of more natural gas cylinders. As well, space to mount additional storage on the truck is very limited.

3. **Loss of power when natural gas storage pressure less than 1000 psi.** Substantial power reduction was reported at low gas pressures, causing drivers to switch to straight diesel before the natural gas supply was exhausted. In an attempt to deal with this problem a larger orifice regulator seat (3/8 inch versus 1/4 inch in the original) was installed at 528,505 kilometres. This modification appears to have resolved the problem, as drivers report improved power at lower gas storage pressures.

4. **Accelerator response problems when shifting.** Drivers generally agreed that the accelerator response on dual fuel was noticeably lagged compared to straight diesel. This required some adjustment in driving technique when shifting. In an effort to improve engine response, Cryogas Engineering moved the natural gas intake from the back of the truck cab to a position immediately upstream from the turbocharger - about 5 feet closer to engine than its former position. Some reprogramming of the on-board computer was also undertaken. After this modification drivers reported that while engine response was considerably improved, it still did not measure up to the diesel benchmark, and remained a nuisance factor. The gas actuator valve itself was therefore moved up as close as possible to the turbocharger in a further attempt to minimize this lag in engine response. Some degree of hesitation still persists, however.

   Another response problem occurs when the driver shifts to a higher gear. Unlike diesel operation, the engine speed is slow to drop when the driver takes his foot off the accelerator during operation in the dual fuel mode. He therefore has to wait longer for the speed to drop to allow him to shift to a higher gear. While this is not a critical problem under most circumstances, it is another aspect of the truck's performance that does not match operation on straight diesel. It may be possible to reduce this problem by re-programming the on-board computer, although this might occur at the expense of increasing hesitation lag time when the driver steps on the accelerator after making his shift. Efforts will be made to solve both of these response problems.

Aside from these specific factors, the drivers were asked whether the Cryogas system was sufficiently developed to be put into commercial service in a fleet operation. The two principal drivers indicated that the system needs further development before it would be acceptable in commercial service, particularly with respect to overcoming the accelerator response (hesitation/lag) problems.

In this regard, one interesting suggestion by one of the drivers was that the system might be better suited to operation with an automatic transmission. Since the driver keeps his foot down on the accelerator even during shifts, the response problems would be eliminated. An additional potential benefit of an automatic transmission might be to extend wear block life in the first stage regulator, since the regulator would no longer be abruptly opening and closing every time the truck shifted gears. The maintenance department of Safeway, however, advises that currently available automatic transmissions are not considered to be appropriate for their highway truck applications.

5.4.2 Fleet Management Assessment of the Demonstration Vehicle

The management personnel of Safeway's Burnaby trucking department who were involved in this project were interviewed at its conclusion concerning their assessment of the performance of the demonstration vehicle. Safeway management was very supportive in dealing with the technical and operational challenges that arose throughout the demonstration project. The company has been particularly active in promotional activities to assist in natural gas/diesel technology transfer, as detailed in Appendix G.

At the beginning of the project, the drivers were felt to be a bit overly cautious in terms of shutting the truck down whenever any minor problem arose, even though they ultimately turned out to be unrelated to the natural gas fuel system on the truck. Over the course of the project, however, both drivers and maintenance shop workers became more familiar and comfortable with the natural gas fuelling system on the truck, especially with respect to gas safety matters.

While the natural gas conversion system is working better now, management feels that it requires further proving and development before it is ready to go into commercial service in a fleet operation. In particular, the following improvements in the conversion system and fuelling stations were identified as being necessary to make the system acceptable to a fleet operation:

- a more reliable first stage regulator;
- a lighter natural gas fuel storage system;

- more natural gas fuelling stations with better access to highway trucks;
- quicker fill times at natural gas fuelling stations.

Safeway will continue to operate the demonstration truck with the goal of proving the viability of the system over the longer term. One particular objective, for example, is to establish whether the IMPCO first-stage regulator is more reliable than the MECO it replaced during March 1990. Another objective is to establish if natural gas has any impact on the interval between engine overhauls.

This project has been the object of considerable interest by Safeway's head fleet management office in Oakland, California as well as by other regional Safeway fleet managers. The company's interest in natural gas as an alternative fuel is primarily driven by its potential for achieving reduced emissions, with fuel cost savings as a secondary benefit.

In mid-1990 Safeway's Burnaby fleet will be ordering about ten new tractors for local operation. These would otherwise be equipped with a 315 HP version of Cummins L-10 diesel engine. Safeway management, however, have expressed potential interest in powering these trucks with a spark-ignition version of this engine (if it is available in a 300 HP version by mid-1991) and having an on-site natural gas station to supply their fuelling needs.

TABLE 5-1: SUMMARY OF MONITORING RESULTS, SAFEWAY TRUCK B121

Quarter	1st	2nd	3rd	4th	TOTAL
Start of period	Apr 6/89	Jul 12	Oct 5	Dec 22	Apr 6/89
End of period	Jul 12/89	Oct 5	Dec 22	Apr 4	Apr 4/90
Total km logged	25,713	16,074	10,303	11,913	64,003
Km on natural gas/diesel	19,174	9,825	5,162	7,696	41,857
% of km on natural gas/diesel	75%	61%	50%	65%	65%
FUEL USE DATA, DUAL FUEL MODE (excl. straight diesel operation)					
Natural gas use, kg	5,033	2,585	1,365	2,110	11,093
Diesel use, litres	4,525	2,339	1,402	1,867	10,133
Total fuel use, litres diesel equiv.	11,268	5,805	3,231	4,694	24,998
Percent natural gas use	60%	60%	57%	60%	59%
Fuel use, km/litre diesel equiv.	1.70	1.69	1.60	1.64	1.67
Fuel use, miles/gallon diesel equiv.	4.80	4.78	4.51	4.63	4.73
ESTIMATED FUEL USE, STRAIGHT DIESEL					
Diesel use, litres	3,006	2,893	2,528	2,116	10,543
Kilometres on straight diesel	6,539	6,249	5,141	4,217	22,146
Fuel use, km/litre diesel	2.18	2.16	2.03	1.99	2.10
Fuel use, miles/gallon diesel	6.14	6.10	5.74	5.63	5.93
TOTAL FUEL USE DATA:					
Total natural gas use, kg	5,033	2,586	1,365	2,110	11,094
Total diesel use, litres	7,531	5,232	3,930	3,983	20,676
Total fuel use, litres diesel equiv.	14,275	8,697	5,759	6,810	35,541
Percent natural gas use	47%	40%	32%	42%	42%
Fuel use, km/litre diesel equiv.	1.80	1.85	1.79	1.75	1.80
Fuel use, miles/gallon diesel equiv.	5.09	5.22	5.05	4.94	5.08

NOTES:
1. Source: spreadsheets contained in Appendix D.
2. One kg of natural gas = 1.34 litres of diesel at equal fuel efficiency, based upon relative lower heating values.

TABLE 5–2: RELATIVE FUEL EFFICIENCY AND COSTS, NATURAL GAS/DIESEL vs. STRAIGHT DIESEL

	STRAIGHT DIESEL	NAT.GAS/ DIESEL	NAT. GAS/DIESEL VERSUS DIESEL
FUEL EFFICIENCY:			
Diesel component			
mpg	6.15	13.08	
km/litre	2.18	4.63	
litres/km	0.46	0.22	
Nat. gas component			
km/kg		4.14	
kg/km		0.24	
Total			
mpg	6.15	5.23	-14.9%
km/litre	2.18	1.85	-14.9%
litres/km	0.46	0.54	17.6%
FUEL COST:			
Diesel component			
cts/l	38.50	38.50	
cts/km	17.67	8.31	
Nat. gas component			
cts/kg		33.50	
cts/km		8.09	
Total			
cts/km	17.67	16.40	-7.2%

ASSUMPTIONS:

Fuel prices are as of April 1, 1990.

One kilogram of natural gas equals 1.34 litres of diesel, based on relative lower heating values.

Relative fuel shares on dual fuel are:

60%	nat.gas
40%	diesel

TABLE 5-3: DRIVER ASSESSMENT OF SAFEWAY NATURAL GAS/DIESEL TRUCK

How would you rate the operation of the truck on natural gas/diesel versus straight diesel, in terms of the following aspects:

	DRIVER:	
	A	B
- starting	3	3
- idling	3	3
- responsiveness	2.5	1
- acceleration	2.5	3
- pulling power	3	3
- shifting	2	1
- noise levels	4	3
- smoothness (vibration)	4	3
- tendency to stall	3	3
- overall drivability	3	2
- odor (or lack of)	5	3
- reliability	3	1
- ease of refuelling	3	3
- refuelling time	2	1
- range	2	1
- fuel storage configuration - space taken up by tanks and their position on truck.	3	2
- switching from diesel to natural gas/diesel	5	4
- switching from natural gas/diesel to diesel	5	4

Please assign a rating to each of these criteria, as follows:

1 = much worse than diesel (or unacceptable)
2 = somewhat worse than diesel (poor)
3 = about the same as diesel (satisfactory)
4 = somewhat better than diesel (good)
5 = much better than diesel (excellent)

6.0 ECONOMICS OF DUAL FUEL NATURAL GAS/DIESEL OPERATION

6.1 Fuel Cost Savings of Demonstration Truck

Based upon current relative fuel prices applicable to the demonstration vehicle, and levels of fuel consumption observed during the two operational modes of the engine in the Safeway truck, the economics of dual fuel natural gas/diesel vs. straight diesel are calculated as shown in Table 5-2. This table indicates that fuel efficiency is substantially reduced on dual fuel versus straight diesel - it takes about 17.5 percent more fuel per unit of distance with natural gas/diesel, amounting to about a 15 percent loss in efficiency. This inefficiency largely offsets the potential fuel cost savings attainable from the lower price of natural gas, resulting in a net cost saving of only about 1.27 cents per kilometre, or about 7.2 percent relative to straight diesel operation.

6.2 Potential Fuel Cost Savings With Natural Gas

However, it must be noted that these economics are based upon a prototype situation, and could be greatly improved in an optimized, large-scale commercial operation. More specifically, there are several means by which the economics could be enhanced:

1. **Optimization of the dual fuel conversion system.** There may be a number of measures which can be taken to improve the fuel efficiency of natural gas/diesel conversion systems. Wartsilavasa, a Finnish company which produces large natural gas/diesel marine engines, claims that by directly injecting natural gas into the cylinders at high pressure, its engines achieve equal efficiency on dual fuel operation versus straight diesel. Alternatively, the new generation of electronically-controlled diesel engines may provide some potential for efficiency improvements, as they allow for diesel fuel injection timing advance modifications.

2. **Reduction of the natural gas fuel price.** If a large fleet such as Safeway were to convert all of its trucks to natural gas operation and

install its own private fleet fuelling station, the natural gas cost per kilogram could be considerably reduced. If the gas were purchased on an interruptible basis, it is estimated that the total cost of gas delivered to the truck, including amortized capital and operating costs of the natural gas fuelling station, could be about 24 cents per kilogram (18 cents per litre of diesel equivalent). The total cost of compression alone is estimated to be in the vicinity of 10 cents per kg.

3. **Conversion to a single fuel, spark-ignition engine.** The use of a spark-ignition engine could displace 100 percent of the diesel fuel, unlike the dual fuel system used in the Safeway truck which used only 60 percent natural gas on average. The complete elimination of diesel fuel consumption by a monofuel natural gas conversion system results in greater fuel cost savings at comparable levels of relative efficiency. On the other hand, however, the use of monofuel natural gas precludes the purchase of interruptible natural gas which is considerably cheaper than firm gas. It is estimated that firm gas for monofuel operation would cost at least 30 cents per kg (22.4 cents per litre of diesel equivalent).

Table 6-1 shows the impact that increased percentages of natural gas use and increased fuel efficiency would have on fuel cost savings relative to straight diesel. While increased percentages of natural gas utilization and increased fuel efficiency show significant opportunity for further reducing fuel costs, they will require the development of more advanced technology than that employed in this demonstration. The factor offering the best immediate prospect of significantly greater fuel cost savings in a dual fuel system is a lower natural gas price achievable through a large-scale private fleet fuelling station using interruptible natural gas. Since this factor is achievable with present technology, there is reason to be optimistic that truly significant fuel cost savings can be realized through the use of dual fuel natural gas/diesel in a commercial transport operation.

For example, one of the largest volume commodity movements by truck in B.C. is the transport of wood chips from sawmills to pulp mills. These chips are carried in "B-train" combinations which operate on a round-the-

clock basis. It is not uncommon for such trucks to use 225,000 litres of diesel per annum. For such trucks even a 20 percent fuel cost saving would translate into a large dollar amount over the course of a year - about $17,300 at the fuel prices stated in the notes to Table 6-1. Such a savings would be attainable even accepting a 15 percent efficiency loss, with only 60 percent of the fuel supplied by natural gas.

Table 6-1 also indicates that monofuel spark-ignition natural gas use would provide greater savings than the base case dual fuel situation in which natural gas provides 60 percent of total fuel use. Thus, the higher level of diesel displacement more than offsets the greater cost per kilogram of using firm gas instead of interruptible gas, as assumed in the dual fuel economics calculation. Given these assumptions, monofuel natural gas offers the same fuel cost savings as a dual fuel system in which natural gas provides 80 percent of total fuel use. Thus the monofuel conversion system may offer greater savings given the current state of technology. Assuming the same 15 percent efficiency loss relative to straight diesel, the hypothetical chip truck would save in excess of $27,300 per year in fuel costs, given the monofuel assumptions detailed in Table 6-1. An increase in time required for refuelling stops may reduce these savings somewhat, unless refuelling could be done during the driver's normal rest periods.

6.3 Conversion Costs

The savings in fuel costs achievable with natural gas use must be balanced against a substantial conversion cost. If a fleet were to convert in the order of 10 identical trucks, substantial savings could be achieved in the conversion cost. Nevertheless, it is estimated that the cost per truck for a dual fuel system with comparable storage (600 litres water capacity) would still be in the order of $20,000 to $25,000 depending on the particular make and model of truck and engine concerned. About half of this cost would relate to the engine conversion system, while natural gas storage cylinders, the mounting system, and miscellaneous hardware and labour charges related to the storage system would account for the remainder of the cost.

At the annual fuel cost savings indicated earlier for high-mileage chip trucks, the cost of the dual fuel natural gas conversion system could be recovered in less than 2 years.

While the costs for a commercialized spark-ignition conversion system for heavy trucks are not yet well-established, prototype work to date indicates that the cost is likely to be at least as high as a dual fuel conversion. In fact, given the requirement for increased natural gas storage to provide adequate range, the cost is likely to be higher, at least until such time as spark-ignition engines are produced in larger numbers. However, as noted in the foregoing discussion, the potential for annual savings is also considerably higher than with a dual fuel system, thereby providing the opportunity for a good payback.

6.4 Longer-term Considerations

Over the longer term there are a number of factors which could alter the current price relationship between natural gas and diesel fuel. On the one hand, many industry observers feel that there is potential for the natural gas price to increase relative to oil prices as the "gas bubble" in the U.S. shrinks. On the other hand, however, the prospect of mandated low-sulphur diesel fuel specifications (0.05 % sulphur) to meet future emissions standards may result in significantly-increased diesel fuel prices. Government taxation policies to encourage the use of clean fuels may also favour natural gas utilization.

More stringent emissions standards may turn out to be a more compelling reason to use natural gas as a fuel for heavy trucks than the potential for fuel cost savings. Indeed, this was the view expressed by Safeway's fleet management. Even so, the foregoing analysis indicates that significant fuel cost savings are achievable through the use of natural gas in higher mileage trucks, providing an added benefit.

TABLE 6-1 RELATIVE FUEL COSTS AT VARIOUS LEVELS OF FUEL EFFICIENCY AND NATURAL GAS USE

CASE 1: DUAL FUEL NATURAL GAS/DIESEL

Relative efficiency vs. straight diesel —>	15% loss	Parity
% Nat. Gas	% Fuel Cost Savings with Natural Gas:	
60%	20.2	32.1
80%	32.8	42.8

Calculations are based upon diesel price of 38.5 cents/litre and an interruptible natural gas price of 24 cents/kg.

CASE 2: MONOFUEL NATURAL GAS

Relative efficiency vs. straight diesel —>	15% loss	Parity
% Nat. Gas	% Fuel Cost Savings with Natural Gas:	
100%	31.6	41.8

Calculations are based upon diesel price of 38.5 cents/litre and a firm natural gas price of 30 cents/kg.

7.0 CONCLUSIONS

The Safeway truck which was converted to natural gas/diesel as part of the Adams demonstration project generally performed fairly reliably, while accumulating more than 64,000 km during the one-year monitoring period. Normally, in this duty cycle it would have logged about 100,000 km annually. Only a minority of the reduction in utilization can be attributed directly to problems with the natural gas fuel system on the truck. The main sources of downtime that were attributable to the system are as follows:

- adjustments and modifications to attempt to reduce accelerator response lag;
- the need to service first-stage regulator wear blocks almost on a monthly basis;
- a faulty solder joint on a circuit board in the on-board computer controlling operation of the dual fuel system.
- driver concerns about abnormal engine temperatures due to modifications in the thermostat function during the conversion. No overheating was actually attributable to the conversion, however.

The range of the truck on dual fuel is generally limited to about 350 km when operating on-highway, necessitating more frequent refuelling. While this range is adequate for local operation, drivers have indicated that greater range for highway operation would be desirable. Greater range, however, would require the addition of more gas storage cylinders, or the use of liquified natural gas (LNG). Most trucks are quite limited in the number of bulky CNG cylinders they can accommodate, while a large proportion of those with sufficient physical space to accommodate enough cylinder storage volume may have their payloads reduced by an unacceptable amount by the added weight of the tanks. For these reasons LNG would be an attractive option for highway trucks.

Another alternative for highway truck operation would be to accept the limited range, but have a network of highway stations specifically designed for easy truck access and large volume, fast fuelling. Ideally, these

stations would be able to consistently provide a 100 kg natural gas fill in less than 10 minutes. During the demonstration the truck typically required about 15 minutes to fuel with 90 to 100 kg of natural gas at the Adams station, and about 25 minutes at stations in Quesnel and Cache Creek, excluding waiting time which may be quite significant on occasion. With the exception of the Adams station, most natural gas fuelling stations are not designed for easy truck access and for large volume, fast fuelling. The Adams station has demonstrated that significant improvements are attainable in these parameters. Ultimately, however, most fleet operators would probably require an on-site fuelling station in order to reduce natural gas cost, travel time to and from off-site public stations and waiting time at these stations.

In the dual fuel mode the truck experienced a 15 percent loss in thermal efficiency relative to straight diesel fuel during highway operation, and a 20 percent loss during local operation. While there is increasing emphasis on emissions reduction as a reason for utilizing natural gas, the efficiency level relative to the benchmark of straight diesel operation will probably have to be substantially improved before it is commercially acceptable. In the view of the Cryogas engineer responsible for the conversion system, there is only limited scope for improving the thermal efficiency of an aspirated dual fuel conversion system. The new generation of electronically-controlled diesel engines may provide some potential for efficiency improvements as they allow for diesel fuel injection timing advance modifications. Ultimately, however, some form of direct injection system will likely be required to improve efficiency, while also reducing emissions and knock potential.

Feedback from the two principal drivers involved in this demonstration project indicates that further development work is required to reduce the accelerator response lag of the dual fuel conversion system installed on the Safeway truck. In addition, it would also be desirable to extend the servicing interval for the first-stage regulator. The replacement of the original MECO regulator with an Impco model appears to have achieved this objective. A single fuel, spark-ignition natural gas engine would probably eliminate both of these problems, but would make the range problem even more critical for highway truck operation unless LNG were available.

Fuel cost savings resulting from the use of natural gas were not large in the case of the Safeway truck, given the increased level of fuel consumption and the purchase of natural gas at higher prices than if the fleet were to have its own natural gas fuelling station. The analysis in Section 6 of this report shows that at fleet natural gas prices, fuel cost savings are substantially increased. Improvements in thermal efficiency relative to straight diesel operation and higher levels of natural gas utilization (attainable through refinements to dual fuel systems or the use of monofuel spark-ignition natural gas engines) would further improve the economics of natural gas use in heavy trucks. Even with present technology, however, the use of natural gas in high-mileage trucks may offer a payback of less than 2 years.

For natural gas to emerge as a significant fuel for heavy trucks, however, developments must take place to address a number of current impediments. These include:

1. **The availability of a suitable natural gas engine from a major engine manufacturer.** Cummins head office has recently issued a directive to the effect that engines which have been modified to operate on alternative fuels will have their warrantees voided, regardless of whether warranty claims are actually judged to be caused by the alternative fuel systems. The Cummins L-10 natural gas engine in its present configuration for bus applications, is not sufficiently powerful for heavy truck applications. Another reason for development of natural gas engines by major manufacturers is to obtain the appropriate certification of compliance with emissions standards. Alternatively, an engine manufacturer could choose to sanction a single or dual fuel conversion natural kit installed and serviced by its dealer network.

2. **Support and service from a major organization.** To date, most conversions of diesel engines to natural gas operation have been carried out by small independent companies. While their pioneering work is commendable, fleets operators will require ongoing support and service matching the quality of that provided to their diesel-powered trucks

before committing to natural gas-powered trucks in numbers. This requirement thus reinforces the need for a heavy-duty natural gas engine or conversion system available from a major manufacturer, complete with full warranty.

3. **The availability of suitable natural gas storage cylinders that are approved by the appropriate regulatory authorities.** While there are several makes of large capacity natural gas storage cylinders that have been imported into Canada, some of them have not yet been officially approved for use in some provinces. Thus, there is a need for the natural gas industry to work toward obtaining approval for large capacity natural gas storage cylinders. As well, cylinder dimensions must allow for a space-efficient mounting configuration such as in clusters, or a single, large diameter vessel.

4. **The development of a high-pressure direct injection system for natural gas or, at a minimum, electronic control over the diesel injection timing** if dual fuel is to become viable in terms of acceptable levels of fuel efficiency, emissions, and higher levels of diesel fuel substitution. Otherwise, single-fuel, spark-ignition may prove to be the more viable method of natural gas fuelling in heavy vehicles.

5. **The development of new fuelling infrastructure for natural gas-fuelled highway trucks.** If CNG is to be used as the storage medium for natural gas, a network of accessible, high capacity, very fast-fill stations will be required, such as in the Hamilton transit operation where 110 kg reportedly can be dispensed in about 4 minutes. Such stations may be difficult to put in place without a guaranteed level of demand for station operators. In addition, the space and weight requirements of CNG storage effectively make it impractical for many heavy trucks.

   As an alternative, highway trucks could use LNG as the storage medium, with fuelling facilities located in their own yards, given the extended range available from LNG. Through its greatly reduced weight and space requirements relative to CNG, the use of LNG storage would also

greatly increase the potential number of trucks that could use natural gas fuelling. For large fleets, it may be viable to have an on-site LNG plant, depending upon individual locational considerations. For an initial demonstration, or smaller fleets, LNG could be trucked from existing natural gas utility peak-shaving plants and dispensed from mobile storage tanks located in the trucking yard.

While indicating that further developments, as detailed in the foregoing list, must take place if natural gas is to emerge as a significant fuel for heavy trucks, this demonstration project has achieved a number of important objectives:

1. **Provided good quality data** on relative natural gas/diesel versus straight diesel fuel efficiency, gas/diesel proportions of fuel use, and operating range during on-road operation of a Class 8 highway tractor.

2. **Demonstrated the successful operation of a first generation natural gas fuelling station specifically designed to satisfy the particular needs of heavy trucks** in terms of accessibility and reduced fuelling times.

3. **Greatly raised the profile of natural gas as a potential fuel for heavy trucks,** generating both international as well as local interest in the demonstration.

4. **Showed that natural gas is a safe and viable fuel for heavy trucks,** allaying some initial concerns by drivers, maintenance staff, and management. After participating in this demonstration project, Safeway has expressed potential interest in acquiring up to 10 spark-ignition natural gas-fuelled tractors that would operate on local routes.

Thus, the John Adams natural gas/diesel demonstration project has achieved its major objectives, as detailed in Section 1.1 of this report.

APPENDIX A

CHRISTIE/ADAMS

NATURAL GAS FUELLING STATION

DESIGN CODES AND

DETAILED PIPING AND ELECTRICAL DESIGN

A.1 Codes and Standards

The following codes and standards were utilized in the design and construction of the Christie/Adams compressed natural gas fuelling station:

ASME - Boiler and Pressure Vessel Code, Section VIII
ASME - Power Test Code, PTC 9
ASTM - Standard Specifications for Materials
ANSI - Standard Specifications for Bolts, Flange and Fittings
CGA - Canadian Gas Association B-149.1
BCML - British Columbia Ministry of Labour, Boiler and Pressure Vessel Act
CSA - Canadian Standards Gas Z-184 M1983
CCAC - Consumer and Corporate Affairs Canada (Legal Metrology)
CTC - Canadian Transport Commission
SSPC - Steel Structures Painting Council

Electrical equipment conforms to the following standards and codes:

CSA C22.1	- Canadian Electrical Code, as amended for use in the province of B.C.
CSA C22.2 No. 4	- Enclosed Switches
CSA C22.1 No. 100	- Motors and Generators
EEMAC M1-6	- Motors and Generators (EEMAC Exceptions to NEMA MG-1)
NEMA ICS-1	- Industrial Control Systems
NEMA ICS-2	- Industrial Control Devices, Controllers and Assemblies
ELECTRICAL BULLETINS	- Province of B.C. Electrical Safety Branch, Safety Engineering Services Division

A.2 Piping

- All components downstream of the compressor are designed for a maximum allowable operating pressure (MAOP) of 4,000 psig.
- Natural Gas Installation Code - CAN/CGA-B149.1-M86 and CSA Z184-M1983 Gas Pipeline Systems are used.
- Piping between compressor and storage is ASTM A106 Grade B 1-1/2" double extra heavy.
- All welded joints meet the requirements of Section 5 of CSA Z184-M1983.
- All butt-weld joints and any repairs have received 100% radiographic examination after the pressure test.
- All weld root and finish beads were examined by the liquid penetrant method.
- All below-grade piping is coated to Shaw Pipe Protection Specification YJ #3 or equivalent (yellow jacket).

- Any defects in the pipe coating were repaired prior to installation.
- All above grade piping excluding stainless steel tubes and fittings have been cleaned, primed and coated with two coats of quality exterior metal paint.
- All below grade portions of the facility are cathodically protected using sacrificial anodes designed to provide a pipe to soil potential between -80 millivolts and -1,500 millivolts and all anode leads and test heads are brought above ground to a cathodic protection test head. Insulating flanges are installed where piping comes above grade.
- All piping is hydrostatically or pneumatically tested according to CAN/CGA B149.1-M86.

A.3 Tubing, Fittings and Valves

- All tubing is ASTM A213 type 16 or type 304 seamless cold drawn stainless steel.
- Minimum tubing wall thickness:
  1/2: - 0.065" wall
  3/8" - 0.049" wall
  1/4" - 0.035" wall
- All tubing fittings are Swagelok 36 stainless steel compression fittings.
- Ball valves are Whitey type 316 stainless steel, 6,000 psig rating.
- Needle valves are Whitey type 316 stainless steel, 6,000 psig rating.

A.4 Electrical

- The service entrance is housed in a separate structure adjacent to the warehouse. The electrical room is designed to house electrical equipment for the original and two future compressors.

- A 347/600 V secondary, 500 kVA transformer is provided with room for a similar second transformer at a later date.
- A 600 V Delta 120/208 V wye, 75 kVA dry type transformer to service the warehouse is also installed.
- A main switchboard containing all necessary protective devices and metering is installed in a motor control centre. Room is available to accommodate two additional motor controls in the future.
- Natural gas for vehicle refueling facilities are classified as Class I, Group D, Division I and II hazard areas; therefore steel conduit is installed within a 15' radius of the dispensing islands.

APPENDIX B

DETAILED CONVERSION AND MAINTENANCE LOG

SAFEWAY TRUCK B121

DETAILED CONVERSION AND MAINTENANCE LOG

SAFEWAY TRUCK B121

February 20 - Monday

The cantilever brackets and deck cylinder brackets were received from Broadway Welders and delivered to Cummins. Mogas was called to arrange delivery of the 94 litre cylinders to Cummins.

February 21 - Tuesday

Safeway truck B121 is now in the Cummins shop. Jim White and John McKinnon of Cryogas Engineering are installing different thermostat housings, an additional water pump, the gas pressure regulators and a heat exchanger. The right fuel tank and muffler have been removed. The four 94-litre cylinders, brackets, valves and thermal release devices arrived from Mogas. The cylinder brackets are narrower than the CNG Fuel Systems brackets which were used for design (3" bolt center versus 3 1/2" on CNG). CNG cylinder brackets will be obtained from A.F. Conversions and the original brackets returned to Mogas.

The cylinder mounting fabrications from Broadway Welders should be painted before installation. The brackets were taken to Lochburn (BC Gas) where they were sandblasted except for the deck bracket which was too large to fit into the cabinet. Cummins will paint the brackets in the afternoon. Cummins weighed the original diesel tank and brackets, and material from Broadway Welders which was to be installed on the truck. Diesel tank: 94 lbs.; 2 hangers: 23 lbs. each including straps; cylinder mounting frame material: 285 lbs.

February 22 - Wednesday

Cantilever brackets for the side cylinder were mounted to the frame. Drawings were sketched of the layout for the tubing, and arrangements were made for a fitter to be at Cummins shop on Friday, February 24 to start work. The exhaust mount channel was raised to allow the muffler and exhaust to clear the side cylinders. There was concern about the length of the cylinders and whether the right cab step would clear the cylinders and valves, or if the step would require modification. Also, there is a problem of right side skid chains and where to hang them if they must be moved to make room for cylinders.

February 23 - Thursday

The rear deck cylinder frame was mounted onto the truck. The tubing fitter was informed that the truck would not be ready for him until Monday, 27th. The spacers on the rear hanger of the left fuel tank were 7/16" thick, while

the plate to mount the deck cylinders was 1/2" thick. The fuel tank was full and concern was raised about holding rear of full tank up with a jack while spacers and plates were interchanged. A decision was made to utilize only two top bolts of rear hanger for deck cylinder support frame. This required grinding thickness of plate to 7/16" to allow plate to slip into position.

February 24 - Friday

Angle washers were obtained to allow bolting cylinder brackets to cantilever channels. Washers required grinding to fit inside channels. Nuts were welded to the angle washers then assembly was welded up inside channels. Once cylinders were in place it would not be possible to hold these nuts on the inside of the cantilever beams.

February 27 - Monday

Sketches were made for mounting refuelling blocks, then taken to the BC Gas welding shop for fabrication.

February 28 - Tuesday

Sketches were made for mounting right side walk plate brackets and taken to the B.C. Gas fabrication shop.

March 1 - Wednesday

The two 118-litre deck cylinders arrived from Mogas. Willie Romero of Prescon arrived to look at installation and see what fittings and material were required for the tubing work. Sketches for the side cylinders lower protection plate hangers were made up and taken to the BC Gas welding shop for fabrication.

March 2 - Thursday

NZIG fill block assemblies were mounted to the sides of the deck cylinder frame. Deck cylinders were mounted. R. Porter of Boiler & Pressure Vessel Safety Branch came over to recertify 118-litre deck cylinders. Ivor Svorinich of Gas Safety Branch came over to look at installation. Ivor suggested two elbows be installed on the vent of the low pressure regulator to keep out water and ice. He also though there should be a heat deflector between the exhaust pipe and the side cylinders. Willie Romero picked up material in the morning and started tubing work in the afternoon. Isolation or NG shut-off valve and plate were mounted to deck frame above fill blocks.

March 3 - Friday

Willie Romero is continuing tubing work. Sketches were made for cylinder valve protection plate mounting brackets and then taken to the BC Gas welding shop for fabrication.

March 4 - Saturday

Willie Romero finished tubing with the addition of a few more tubing clamps. Lugs were welded on the right hand side of cylinder frame to accept the step. Additional brackets were welded to the left side chain hanger to hold the right chains as well. A general inspection of the truck was completed before driving over the Christie/Adams station to fuel with natural gas. The truck was then driven to Christie/Adams for the first fill of gas (509,999 km). It was found that the brackets holding the NZIG fill blocks required holes to allow the refuelling probe to fully enter the receptacle. These were drilled. Two dispensers were connected to right side refuelling blocks and fuelling started.

After about 2 minutes, pressure was about 1,000 psi and frost was forming on the tubing downstream from the receptacles (photograph 2-24). After a few more minutes the frost disappeared. At completion of the fill the cylinders were warm to the touch. Using the two dispensers, fuelling took about 15 minutes to reach over 3,000 psi.

Snoop was used to detect gas leaks. A few were found and corrected by tightening the fittings. A few leaks were also observed at the cylinder valve and thermal release-to-cylinder connections, but these stopped as the pressure increased. It is assumed this was due to the O-rings being forced into position by the gas pressure. The truck was then driven back to Cummins shop and parked outside for the weekend.

March 6 - Monday

An electronic gas sniffer was used on the truck gas equipment to detect any small leaks. A very small leak was detected at the thermal release device at the back end of the lower outside cylinder. The truck was driven up the Gagliardi Way hill to check the cooling system operation and ensure the gas control system was switching at the correct time.

March 7 - Tuesday

The truck was on the Cummins dyno most of the day for mapping of the gas fuel curve by Cryogas. The leaking thermal release device was repaired and the system was checked again with the electronic sniffer. No further indication of gas leakage was found. Sketches were made for the right side walk plate and taken to the BC Gas welding shop for fabrication.

March 8 - Wednesday

The truck was on the Cummins dyno again. The cylinder valve protection plate mounting brackets were picked up from the BC Gas shop.

March 9 - Thursday

Cummins installed the cylinder valve protection plate mounting brackets, lower cylinder protection plate brackets, and right side walk plate. Cryogas modified the water pipes to prevent the hoses from slipping off.

After lunch the truck was back on the Cummins dyno for further adjustments to the fuel map and cooling system.

March 10 - Friday

The truck was checked once again with the electronic sniffer for gas leaks, but none were found. This was in response to a strong smell of hydrocarbon fumes in the dynamometer room where the truck was parked overnight. A mechanic at Cummins later said that they had received a fuel delivery earlier in the morning and this always causes a strong odour of hydrocarbon fumes in the dynamometer room when the doors are closed.

The cylinder valve protection plate was installed and trimmed to fit. The grab handle used to climb up on the right side of the truck was installed. Willie Romero installed the wiring for the fuel gauge in the cab. A Safeway mechanic picked up the truck and drove back to the Safeway yard.

March 13 - Monday

The truck is now at Safeway. The Safeway shop is usually very busy on Monday and this day was no exception. Safeway wants to install a good seat for riders before the truck goes out. The mechanic said the engine temperature didn't come up when he drove truck over from Cummins on Friday. Cryogas said this is expected and normal due to the cooling system changes. Arrangements were made with Willie Romero to complete installation of the cab fuel gauge tomorrow.

March 14, Tuesday

Willie Romero is installing the fuel gauge in the cab of the truck. Safeway mechanic, Tom, assisted with electrical connection to a switched power source. Measurements and a sketch were made for the cylinder bottom protection cover. Safeway has installed a new passenger seat. The truck is scheduled for a run out to Abbotsford tomorrow.

March 15 - Wednesday

The truck will be pulling a full trailer out to Abbotsford today. Stan Murray will be driving. The truck went first to the weight scales in North Delta. Unlike operation on diesel, there was a lack of black smoke when starting up and when shifting gears. This first trip was uneventful.

March 16 - Thursday

The truck was in the Safeway shop for repair of the radiator lower hose which was rubbing on the alternator pulley when the engine torque twisted the frame. The hose was repositioned and a support clamp was fabricated to hold it in position.

March 17 - Friday

Truck B121 delivered a trailer to North Vancouver and another trailer to Abbotsford. Trips were uneventful. No problems were encountered.

March 20 - Monday

Trips around town have been uneventful, therefore John McKinnon is riding with John Van Houton on the regular run to Prince George.

The truck left Burnaby about noon (510,492 km) and arrived in Cache Creek about 5:30 p.m. About 200 psi of gas was left in the cylinders. The truck took on 93.3 kg of NG in 23 minutes before continuing onto Quesnel.

On arriving at Quesnel (511,158 km), all cylinder pressure gauges were reading virtually zero. the truck took on 109 kg of gas in 18 minutes. The truck arrived in Prince George about 1:30 a.m., March 21. The truck was at maximum GVW when it left the Safeway yard. In fact, it was originally overweight on the trailer axles which were slid back in an attempt to distribute the load forward. A couple of pallets had to be removed to arrive at the legal weight. It should be noted that the truck axles were not overweight and the extra weight associated with the natural gas cylinders did not affect the legal load.

March 21 - Tuesday

The truck left Prince George and returned to the Safeway yard in Burnaby pulling a virtually empty trailer. Refuelling was again at Quesnel and Cache Creek. The truck did not refuel in Prince George. The return trip appeared to indicate a significant increase in fuel economy as it was noticed that the cylinders still contained 1,500 psi when the truck arrived at Christie/Adams. The entire trip was again uneventful. The power level was the same as diesel, but there was a small hesitation when shifting gears. When the fuel pedal is pushed down after a shift, there is a momentary hesitation until the engine again was producing full power.

March 22 - Wednesday

John McKinnon of Cryogas was riding with the truck today to correct the hesitation concern. Changes were made to the natural gas fuel map in the electric controller.

March 23 - Thursday

The cylinder mounting and bracket bolts were given a check and tightened further to ensure the installation was secure. The lower cylinder cover was installed to protect the composite reinforcement on the cylinders from rock damage which may occur particularly during the winter months.

March 29 - Wednesday

Instruction to Safeway mechanics was given by way of a video on natural gas cylinder safety tests and a discussion of the Adams project in general. The presentation then continued outside at the truck where John McKinnon explained the operation of the natural gas equipment and the changes made to the cooling system. The mechanics were also made aware of the natural gas valves and the manual shut-off valve.

March 31 - Friday

Safeway has received a number of new 50-foot trailers which have the hitch pin set back 36" from the front of the trailer rather than the older standard distance of 30". The new longer trailers just touch the deck cylinder braces; therefore the braces require modification. Arrangements were made to modify the braces in the Safeway shop on Monday, April 3. Changing the angle of the deck braces would also require some shifting of the refuelling blocks, therefore the opportunity will be taken to rotate the blocks 180^{o} so that the receptacle is at the bottom of the refuelling block and the gas passage hole would be on the top side of the port. This is to prevent dirt and dust which may enter the receptacle port from falling into the gas passage hole and possibly cause problems downstream with the check valve seal. There is a large amount of dust, water and salt spray flying around this area of the truck. This is an area for further improvement.

April 3 - Monday

(512,287 km, 24.6 hrs.) The deck cylinder braces were modified by reducing the angle somewhat and utilize another set of exiting frame holes about 12" forward of the original holes. The refuelling block and mounting plates were rotated 180^{o} and remounted on the deck bracket. These changes also required some changes to the gas tubing.

April 4 - Tuesday

Changes to the gas tubing were completed by 1:00 p.m. the pressure gauge on the right side now sticks out but this will be changed tomorrow morning when the truck refuels at Christie/Adams.

April 5 - Wednesday

The truck was taken out today on town deliveries with Cryogas adjusting the fuel program to reduce the hesitation problem. The natural gas pressure gauge location was changed and a plug added to the bleed-off valve to prevent tampering. No problem with clearance now with the new longer trailers.

April 13 - Thursday

John McKinnon changed shutterstat operation from 170 to 180 degrees F. The temperature readout was found to be consistent with the Murphy gauge.

April 24 - Monday

(518,615 km, 103.3 hrs.) The truck has been tagged out at Safeway because of a reported gas leak around one of the deck cylinder valves. This was checked and a leak was found on the lower fitting of the tubing cross. The fitting was found to be slightly loose and was thus tightened to correct the leak. A couple of other fittings in the cross area were also tightened. These fittings will be watched closely to ensure there isn't a problem. The truck is scheduled to make a run to Kamloops and be back Thursday morning. Arrangements were made to give all gas equipment a thorough check on Thursday.

April 27 - Thursday

(519,416 km, 113.6 hrs.) The truck had just returned from a trip to Kamloops. The cylinder covers were removed and all brackets, hangers and tube fittings were checked for tightness. A bracket and hanger bolts were tight. A couple of the tubing fittings behind the cylinder front cover were found to require slight tightening. The fittings around the cross which were tightened on the April 24 were still tight.

May 24 - Wednesday

(527,344 km, 196 hrs.) A call was received concerning a leaking natural gas receptacle on the truck. This was investigated but the leak disappeared after refuelling at Christie/Adams. Probably a piece of foreign material interfered with the O-ring seat in the check valve and was blown out by the refuelling processes. In any case, the problem did not re-occur.

May 29 - Monday

(528,505 km, 208.4 hrs.) The truck returned from an out-or-town trip and was been tagged for lack of power. Cryogas will be investigating tomorrow. Pressure in the cylinders was approximately 600 psi.

May 30 - Tuesday

(528,505 km, 208.4 hrs.) While the truck was available, the cylinder mounting was once again checked for tightness. Everything was tight. The O-rings on the receptacle plugs were showing signs of wear and were replaced.

Cryogas increased the temperature setting on the cooling thermostats, inspected and rotated the seat on the high pressure regulator and increased the low pressure regulator seat size to 3/8" from 1/4". The original 1/4" seat orifice was restricting gas flow to the engine, particularly when cylinder pressure was below about 1,000 psi. Gas pressure to the engine should be 3.3 to 3.4 psi at all times but was found to be 2.4 psi when the cylinder pressure was around 600 psi. This was not noticed previously because the cylinders were always filled before going out on a test run.

June 13 - Tuesday

(532,339 km, 236.8 hrs.) The truck had been tagged for an engine noise and coolant leak. It was found that the coolant leak was coming from the area of the cab heater and not related to the engine conversion. The engine noise appeared to be from the front of the engine and was an accessory noise rather than from inside the engine. It was traced down to probably being the cooling fan clutch hub as it was very loose and had been transferred from the original engine. This was later confirmed when the assembly was replaced.

June 15 - Thursday

The gas inlet tube was relocated closer to the turbocharger to correct a persistent hesitation problem. The hesitation is particularly irritating to the drivers when they are changing gears.

June 21 - Wednesday

(532,426 km, 238.8 hrs.) The program map in the dual fuel controller was changed slightly in an attempt to further improve hesitation problems. Hesitation is now almost gone.

June 29 - Thursday

Eve Savory from the CBC "National" news and a cameraman were at the Christie/Adams station to obtain some film and information on the Safeway truck for use on a future show. Signs were mounted on the truck for the CBC news taping session. Interviews were shot with Stan Murray, John Adams and Mike Sinclair. Film was taken of the truck entering the station, refuelling and inside the truck cab.

July 10 - Monday

The engine was reported to have been overheating last week. Once going up the snow shed hill on the Coquihalla Highway and once on level ground. a new driver was driving the truck and may not be aware of the normal operating temperatures. The normal operating temperature is about 205^{O}F according to Ron Pilat, the usual driver. Ron hasn't had an overheating problem.

July 11 - Tuesday

Cryogas doesn't feel there is a problem with the engine temperature. Apparently Ron Pilat had the former diesel engine in the truck cut out at 210^{O}F.

July 14 - Friday

John McKinnon said Ron Pilat has just returned from Prince George without an overheating problem.

July 20 - Thursday

(541,712 km, 287.8 hrs.) The Murphy temperature switch gauge was found to be set too low and cutting out at 210^{O}F. This was reset to 220^{O} which is the normal setting. Stan Murray rode up to Prince George with Paul Grimson, the new highway driver, and recorded the thermocouple temperatures on various parts of the engine. The highest was 214^{O}F which occurred between Cache Creek and Clinton. Stan noted that the fan is on most of the time but the shutters are usually closed.

There was a concern about erratic engine operation but this turned out to be caused by a sticking governor operating rod.

The natural gas dispenser at the Christie/Adams station has cut out when two refuelling probes are used. This occurs when the cylinder pressure is between 700 and 1000 psi. The dispensers are restarted and filling continues normally. The moisture content of the gas has increased lately, which may be creating a freezing problem downstream from a restriction on the truck.

July 21 - Friday

The Federal Minister of Energy, Mines and Resources, J. Epp, was at the Christie/Adams station to announce the BC Transit Project and an extension of the NGV Program for B.C. He was very interested in the Safeway truck. Stan Murray gave him a good description of the truck and its operation.

July 24 - Monday

Willie Romero modified two refuelling blocks on the right side of the truck. The original check valves were removed and replaced with a higher flow Prescon type. The original check valves had a broken spring, a bent spring and a fatigued O-ring in about 4 months operation. The check valve change was made to eliminate a restriction in the refuelling piping and also reduce the tendency to freeze during refuelling.

August 8 - Tuesday

Paul Grimson reported that the engine overheated on the Coquihalla Highway east of Merritt last week. It was operating at 210^{O}F, then suddenly went up to 220^{O}F and the buzzer came on. Also, the engine lost power a couple of times last week but now seems to be all right. There was nothing found that would have caused either of these problems, but the fan is still operating while the shutters are closed. The fan is controlled by a 170^{O}F sensor in the hot water outlet of the engine, while the shutters are controlled by a 120^{O}F sensor in the cold water outlet of the radiator.

August 31 - Thursday

Stan Murray reported erratic RPM during natural gas operation. Changed gas solenoid to a new switch.

September 5 - Monday

John McKinnon said that Paul Grimson has reported some problems with the truck. Apparently there was a backfire in the exhaust system, the engine speed increased when shifting gears at one point, and the truck wouldn't start on diesel or gas one day. John found that the hand throttle cable may have been holding the pump lever. The problems seemed to appear and then disappear.

September 15 - Friday

John McKinnon said the truck wouldn't start the other day. The fuses in the natural gas control system were removed and the engine still wouldn't start. The Safeway mechanics investigated and found that a relay in one of the truck electrical circuits was shorting out to ground. This caused a low voltage condition in the electrical system which resulted in the fuel solenoid closing and not allowing fuel to the diesel fuel pump.

A small piece of metal had broken off inside the relay and was bouncing around, sometimes shorting out and reducing the voltage in the electrical system. This was probably the cause for the previous mysterious operating problems as low voltage would cause problems with the microprocessor.

September 25 - Monday

Norm Engemoen, Safeway Trucking Department Manager, presented a video of the truck at the Safeway Distribution meeting in Napa, California. This video had been prepared by Safeway during the previous weeks. There was considerable interest shown by some of the large trucking companies which attended the Safeway meeting the following day. Joe Haddon attended this meeting at Safeway's request to answer technical questions on the project.

October 13 - Friday

The truck started to have unusual operating problems a couple of weeks ago when the starter was changed. John McKinnon was over to Safeway to investigate and found that the ground wire for the microprocessor, which was originally connected to a starter mounting screw, had been connected to a terminal on the starter relay. After this was corrected, the starter and the gas system functioned correctly.

October 19 - Thursday

The relief valve downstream of the high-pressure regulator was leaking due to the regulator bypassing. A Safeway mechanic disassembled the regulator to rotate the seal block, but found the mating orifice seat was damaged. John McKinnon obtained a new orifice and the regulator was reinstalled. This seating problem has occurred a few times with this regulator.

October 30 - Monday

A new driver has been operating the truck and reported the engine overheating. A discussion was held at the Safeway shop and it was agreed upon that the engine as set, operates at a higher temperature under light load than the diesels, but when under heavy load the temperatures are comparable. One of the peculiarities of the cooling system is the fact operates almost constantly, independent of the shutters which are usually closed. This will be changed to the normal mode of operation which has the shutters open before the fan operates at about 195^{O}F. This should maintain the engine temperature at the same range as the normal diesel engine and reduce concern. As well, reducing operation of the fan should hold fuel efficiency.

October 31 - Tuesday

Operation of the fan and shutters was changed and according to Stan the engine temperature is now similar to the rest of the fleet. The shutters are now opening before the fan which operates at 195^{O}F.

November 17 - Friday

The truck was put on the dynamometer at Cummins B.C.. to compare the power on dual fuel to that on diesel. It was found that the power on dual fuel was about 40 hp higher than diesel at 200 rpm, although at 2100 rpm the power levels were very similar. In general the power on dual fuel between 1700 and 2000 rpm was significantly greater than diesel, which necessitated bringing the dual fuel power level back into line with that of diesel.

November 21 - Tuesday

The project signs were reinstalled on the truck. These had been removed for permanent painting to replace the temporary plastic which had been installed in June. Also a check was made of the cylinder mounting and brackets prior to winter operation. The installation was found to be secure and a check of the aluminum cylinder protection cover under the cylinders did not indicate road debris damage. The O-rings on the right side receptacle plugs were changed, the left side appeared to have seen little use. The gross vehicle weight of the truck has now been raised to 47,000 kg to allow operation with the new tri-axle trailers.

November 23 - Thursday

The truck was driven to Howe Sound Secondary School at Squamish to demonstrate the technology to the students.

November 27 - Monday

The truck was at Cummins today to move the gas control valve closer to the turbocharger, which is anticipated may eliminate entirely the hesitation when shifting. Also the power level will be checked on the dynamometer after the map in the microprocessor has been changed.

December 19 - Tuesday

The high pressure regulator seal block was checked and found to be in poor condition. The seal block and orifice were changed. A small leak around a plug on the regulator was also corrected.

December 27 - Wednesday

The truck developed a problem on a trip to Kamloops and had to be towed back from the toll booth on the Coquihalla Highway. Apparently the engine accelerated up to the governor point during a gear change.

1990

January 8 - Monday

Suppression was installed on all solenoid circuits in an attempt to eliminate the intermittent problem of the engine running away during gear changes. The truck had not operated since the December 27 problem on the Coquihalla Highway.

January 11 - Thursday

The truck returned from Prince George last night. The driver indicated that the engine was low on power between 1500 and 1900 rpm. The truck is now in the shop for repair of a broken rear spring.

January 16 - Tuesday

(569,732 km, 477.7 hrs) The truck was taken to Cummins to be checked on the dynamometer to determine the extent of the power loss. The latest comments from the regular town driver are:

- at 1500 rpm power is down on dual fuel;
- at 1600 rpm to 1900 rpm the power is normal, then drops (this occurs in cycles when trying to maintain a constant speed);
- from 1900 rpm to 2000 rpm the power is slightly greater than on diesel.

On the dynamometer the truck was found to be producing 30 hp more than diesel at 2000 rpm. The high pressure gas regulator seal block was rotated once again which corrected the problem, although the power level at 1900 rpm was high.

Changes to the microprocessor map brought the power curve to a very close match with diesel. During an extended run it was noticed that the power level dropped due to a signal level drop from the microprocessor. The microprocessor controller was removed to be checked on the bench.

January 22 - Monday

The controller was bench-tested but no problems were detected. It was reinstalled on the truck, but a problem was immediately evident and it was removed again.

January 24 - Wednesday

A loose solder joint was found on a microchip. This was repaired and the controller was reinstalled. The truck was run again on the Cummins dynamometer without problems.

January 29 - Monday

The controller is now experiencing problems during gear changes. It doesn't allow the engine rpm to drop consistently, therefore upshifts are a problem which sometimes results in missed gear changes.

January 31 - Wednesday

The information in the microprocessor was downloaded to the lap-top computer to ensure all information points were intact and nothing had been lost. A small change was made to the information map in the low rpm range.

February 12 - Monday

The truck has returned from a trip to Prince George. Apparently the truck is difficult to drive now because engine revs do not drop predictably when changing gears. Both drivers have noticed this problem.

February 19-20 - Monday, Tuesday

(571,456 km, 497 hrs.) The low pressure regulator, solenoid valve and linear actuator gas valve were moved to the front c^{f} the engine, close to the turbocharger inlet. The low pressure regulator was found to have some broken parts and was repaired. The drivers now reported that the hesitation after shifting was now almost undetectable.

March 5 - Monday

(573,942 km, 520.8 hrs.) The high pressure regulator was found to be operating erratically which was corrected by rotating the seat block again.

April 16 - Monday

An Impco HPR-501 high pressure regulator was installed and adjusted to 40 psig outlet pressure. This regulator replaces the MECO type P-1-DD multi-seat regulator which required almost monthly seat block rotations. The Impco regulator has been reliable on other applications but on a previous application with similar dual fuel conversion equipment, problems were experienced. It remains to be seen how it performs in this application.

April 20 - Friday

The suppression installed on the solenoid circuits on January 8th was disconnected. This was done to eliminate any doubt that the engine run-away problem experienced in December and January was caused by anything other than the poor microchip solder joint.

The Merritt natural gas compressor was removed recently and the Cache Creek Texaco Station is to be closed on April 22nd. Compressed natural gas will be made available as soon as possible at these sites, but in the interim the truck will have to switch to diesel at some point on these Interior trips.

May 3 - Thursday

There has been no reoccurrence of the engine run-way problem since the suppression circuits were disconnected. This confirms that the problem was caused by the poor solder joint.

Also, the new Impco regulator has so far performed without problems.

FINNING
YOUR CATERPILLAR DEALER
Head Office: 555 Great Northern Way, Vancouver, B.C. V5T 1E2
Phone: (604) 872-4444 • Fax: (604) 872-2994 • Telex: 04-50817 • Cable Address: FINTRAC

S·O·S
SCHEDULED OIL SAMPLING

WEAR ANALYSIS REPORT

MAR 20/90

CDA SAFEWAY BURNABY
MAC
7185 - 11TH AVENUE
BURNABY
BC V3N 2M5
PHONE 522 1133 NETWORK CODE 000

UNIT NO. B 121
EQUIPMENT MAKE CUM MODEL 350 SERIAL NO. 2440534 COMPARTMENT ENGINE
COMPONENT 1317710

CURRENT RESULTS

OIL SAMPLE INFORMATION				PHYSICAL ANALYSIS			WEAR ELEMENTS												BASE ELEMENTS			INFRA-RED ANALYSIS	
SAMPLE NO	HRS/KMS ON UNIT	HRS/KMS ON COMP	LITRE OIL ADDED	SAE OF OIL USED	WATER %	GLYCOL %	SILICON (UNIT)	IRON	ALUM	CHROME	NICKEL	COPPER	LEAD	TIN	SILVER	MAG	MOLY	SODIUM	BORON	ZINC	CALCIUM	% SOOT	% ALLOW OXIDAT
109030	574421		36	40	0	N														>	>	105	68
DATE TAKEN (Y.M.D)	DATE RCVD (Y.M.D)	HRS/KMS ON OIL	OIL CHANGED	SAE OF SAMPLE	SALT	FUEL OIL																TAN	TBN
900312	900319	27000	Y	L 40		0	10	61	4	3.5	1	10	41	0	0	29	0	20	11	500	500		

SOOT CONTENT IS HIGH. DIRT CONTENT AND WEAR RATES ARE NORMAL. CHECK AIR INDUCTION SYSTEM, OPERATING TEMPERATURES AND RESAMPLE AT NEXT SERVICE PERIOD.

SS

PREVIOUS RESULTS

SAMPLE NO	HRS/KMS ON UNIT	HRS/KMS ON COMP	LITRE OIL ADDED	SAE OF OIL USED	WATER %	GLYCOL %	SILICON (UNIT)	IRON	ALUM	CHROME	NICKEL	COPPER	LEAD	TIN	SILVER	MAG	MOLY	SODIUM	BORON	ZINC	CALCIUM	% SOOT	% ALLOW OXIDAT
62766	547116		35	40	0	N														>	>	78	56
DATE TAKEN (Y.M.D)	DATE RCVD (Y.M.D)	HRS/KMS ON OIL	OIL CHANGED	SAE OF SAMPLE	SALT	FUEL OIL																TAN	TBN
890810	890815	37000	Y	M 30		0	4	53	2	2.4	5	13	27	2	0	25	0	16	3	500	500		

NORMAL DIRT AND METAL WEAR RATES. NO SERIOUS DEFECTS INDICATED. SUGGEST TO RESAMPLE AT NEXT SERVICE PERIOD.

B-17

SAMPLE NO	HRS/KMS ON UNIT	HRS/KMS ON COMP	LITRE OIL ADDED	SAE OF OIL USED	WATER %	GLYCOL %	SILICON (UNIT)	IRON	ALUM	CHROME	NICKEL	COPPER	LEAD	TIN	SILVER	MAG	MOLY	SODIUM	BORON	ZINC	CALCIUM	% SOOT	% ALLOW OXIDAT	% ALLOW SULPHUR
31457	528503			40	0	N														>	>	41	42	4
DATE TAKEN (Y.M.D)	DATE RCVD (Y.M.D)	HRS/KMS ON OIL	OIL CHANGED	SAE OF SAMPLE	SALT	FUEL OIL																TAN	TBN	
890526	890530	18000	N	H 30		0	4	27	2	1.0	3	8	7	0	0	26	0	12	1	500	500			

NORMAL DIRT AND METAL WEAR RATES. NO SERIOUS DEFECTS INDICATED. SUGGEST TO RESAMPLE AT NEXT SERVICE PERIOD.

LS

SAMPLE NO	HRS/KMS ON UNIT	HRS/KMS ON COMP	LITRE OIL ADDED	SAE OF OIL USED	WATER %	GLYCOL %	SILICON (UNIT)	IRON	ALUM	CHROME	NICKEL	COPPER	LEAD	TIN	SILVER	MAG	MOLY	SODIUM	BORON	ZINC	CALCIUM	% SOOT	% ALLOW OXIDAT	% ALLOW SULPHUR
821392	510210			40	0	N														>	>	15	75	5
DATE TAKEN (Y.M.D)	DATE RCVD (Y.M.D)	HRS/KMS ON OIL	OIL CHANGED	SAE OF SAMPLE	SALT	FUEL OIL																TAN	TBN	
890314	890411	7846	Y	L 40		0	9	37	3	3.1	4	16	10	0	0	24	0	23	2	500	500			

SAMPLE NO	HRS/KMS ON UNIT	HRS/KMS ON COMP	LITRE OIL ADDED	SAE OF OIL USED	WATER %	GLYCOL %	SILICON (UNIT)	IRON	ALUM	CHROME	NICKEL	COPPER	LEAD	TIN	SILVER	MAG	MOLY	SODIUM	BORON	ZINC	CALCIUM	% SOOT	% ALLOW OXIDAT	% ALLOW SULPHUR
745177	474708			40	.1	N		A										A		>	>			
DATE TAKEN (Y.M.D)	DATE RCVD (Y.M.D)	HRS/KMS ON OIL	OIL CHANGED	SAE OF SAMPLE	SALT	FUEL OIL																TAN	TBN	
880309	880615	32000	Y	L 40		0	8	75	2	3.0	0	37	12	0	0	37	0	54	6	500	500			

CUSTOMER'S COPY

< LESS THAN > GREATER THAN A - ABOVE NORMAL (SAFE LEVEL) H - HIGH (NEEDS ATTENTION) P - POSITIVE N - NEGATIVE T - TRACE

APPENDIX C

DRIVER OPERATING

AND

DATA COLLECTION INSTRUCTIONS

CANADA SAFEWAY LIMITED - NATURAL GAS FUELLED TRUCK

DRIVER DATA COLLECTION INSTRUCTIONS

Reports on Safeway's experience with natural gas as a highway trucking fuel will be published by Energy, Mines and Resources Canada. Careful data collection by the drivers is an important requirement. In addition to routine monitoring by Safeway, data will be compiled and analyzed by Christie/Adams Distributors Ltd., who operate the Burnaby fuel station, and are managing the ENERDEMO CANADA Program.

The driver should complete a blue data card every time the truck takes fuel. Several data items are identical to those on the standard data card, and should be completed in the normal manner. Both natural gas and diesel may be recorded on the same card, but only if both fuels are taken at the same location. Do not record fuel purchases from two locations on a single card.

Do not complete the "Fuel Switches" section of the card if the truck is operating continuously on natural gas. If a decision is made to operate on diesel, to switch back to natural gas, etc., please note the odometer reading and explain the switch on the back of the card.

Please record GVW as convenient, once on each outbound trip with the trailer loaded, and once on each return trip with the trailer at its minimum weight for the trip. If there is a cargo backhaul (other than empties), note this on the back of the card.

From time to time we expect to interview drivers of the demonstration truck. However, should you have any comments or observations which you think would be of interest, please feel free to contact us directly. Phone Peter Midgley or Mike Sinclair at 682-8691.

NATURAL GAS FUELLING INSTRUCTIONS

Natural gas refuelling is possible from either side of the truck. There are two fuelling receptacles on each side, permitting the use of both hoses at some fuelling stations.

Before removing the receptacle plugs, wipe away any dirt or grit that may have accumulated; similarly, ensure the station fuelling probes are clean and in good condition. Wipe if necessary, and if the O-ring shows signs of wear, replace it from the truck kit box (lubricate lightly) or bring it to the attendant's attention.

When inserting the probe into the receptacle, a gentle twist is helpful. When the probe is fully inserted, turn on the gas valve and start the gas flow. Natural gas will flow until a tank pressure of about 3000 psi is reached. When the dial on the dispenser slows noticeably, it is reasonable to turn off the gas. Note, however, that this is not necessary -- you cannot overfill the tanks.

Close the gas valve slowly. While doing this a small amount of pressurized gas will be vented from the receptacle, thereby allowing the probe to be removed. Ensure the receptacle plug is clean and the O-ring in good condition, and reinsert the plug into the receptacle.

over ...

... continued - page 2

While it is unlikely to happen, should gas appear to be leaking from the receptacle, there could be a problem with the check valve. Simply close the round black valve below the receptacle, and bring the matter to the attention of the Repair Department.

Every fuelling station has an emergency shutoff valve or button in the refuelling area. Make a point of locating it, in case you ever have cause to use it.

Also note that the truck's fuel storage tanks can be isolated from the engine by turning the black handle ball valve about one-quarter turn. Should the truck ever be involved in a serious accident, it would be a reasonable precaution to isolate the tanks. Similarly, the tanks should be isolated before any major engine or mechanical repairs.

FUEL SYSTEM INSTRUCTIONS

Assuming that the gas cylinders are charged, and the main gas valve is turned on, the vehicle is ready to operate on natural gas/diesel dual-fuel. With gas available, the gauge mounted on the high pressure regulator, located behind the cab, will read approximately 60 psi.

To prepare for dual-fuel operation, it is simply necessary to put the dash-top mounted switch into the "ON" position. This should be done either when the engine is off, or at idle.

The dual-fuel system will come into operation at about one-quarter load; below this load the system operates the engine on 100 percent diesel. As the load increases, the system reduces diesel fuel, and feeds natural gas into the intake manifold to make up for the diesel reduction.

When the system is operating, the blue light adjacent to the system selector switch will be lit. Some reduction in engine noise may be noticed. Otherwise, operation on dual-fuel will differ little from diesel operation.

As the natural gas supply is exhausted below the last 5 percent or so, there will be a gradual loss of power. At this time, as at any other time, reversion to diesel operation may be accomplished by switching the dash-mounted switch "OFF". NOTE: This switch should not be done under load, as the engine will stall and require re-starting.

The engine cooling system has been modified for natural gas operation, and operating temperatures will tend to be lower than normal. Also, the shutter-stat has been modified and the radiator shutter will normally be open, even at lower engine temperatures.

For maximum efficiency on dual-fuel, engine speed should be kept in the 1500 to 1900 r.p.m. range.

PRODUCT CODE #527

CLEAR DIESEL _____ LITRES

NATURAL GAS _____ KILOGRAMS

BULK OIL _____ LITRES

CANNED OIL _____ LITRES

DATE _____ AM PM

UNIT # _____

ODOMETER _____

FUELER _____

STATION _____

FUEL SWITCHES (circle) odometer

1. TO GAS TO DIESEL _____

2. TO GAS TO DIESEL _____

3. TO GAS TO DIESEL _____

4. TO GAS TO DIESEL _____

(please explain switches on back of card)

GVW _____

LOCATION _____

ODOMETER _____

Please note any fuel problems on the back of card, along with date and odometer reading.

NOTE: After data entry in truck office, please retain card for collection by ADAMS EMERDEMO PROJECT.

APPENDIX D

DETAILED MONITORING DATA

SAFEWAY TRUCK B121

TABLE D-1: FIRST QUARTER NATURAL GAS/DIESEL MONITORING DATA, SAFEWAY TRUCK B121

							CUMULATIVE DATA (Since filling at 512,591 km) 1 kg gas = 1.34 litres diesel				
DATE (1989)	ODOMETER READING km	SWITCHED TO: DIESEL	SWITCHED TO: NAT.GAS	FILL TIME mins.	FUEL TAKEN ON: NAT.GAS kg	FUEL TAKEN ON: DIESEL litres	LOCATION	FUEL USE: NAT.GAS kg	FUEL USE: DIESEL litres	TOTAL DIESEL EQUIV. litres	DISTANCE BETWEEN DOMETER READINGS km	CUMUL. DISTANCE TRAVELLED km
April 6	512,591				96.172		Adams					
April 7	512,600		Y								9	9
	512,821				73.957		Adams	74.0		99.1	221	230
	512,962					90	Bby. yard	74.0	90.0	189.1	141	371
April 10	512,962							74.0	90.0	189.1		371
	513,189							74.0	90.0	189.1	227	598
April 11	513,209	Y						74.0	90.0	189.1	20	618
	513,216		Y		98.933		Adams	172.9	90.0	321.7	7	625
	513,478				63.948		Merritt	236.8	90.0	407.4	262	887
April 12	513,820	Y						236.8	90.0	407.4	342	1,229
	513,889		Y		85.288	295	Merritt	322.1	385.0	816.6	69	1,298
April 13	514,144	Y				(est)		322.1	385.0	816.6	255	1,553
April 13	514,152		Y		75.290		Adams	397.4	385.0	917.5	8	1,561
April 13	514,238				30.264	42.3	Adams	427.7	427.3	1,000.4	86	1,647
April 14	514,560	Y						427.7	427.3	1,000.4	322	1,969
	514,577		Y		98.306		Cache Ck.	526.0	427.3	1,132.1	17	1,986
	514,904				94.976		Quesnel	621.0	427.3	1,259.4	327	2,313
	515,154				78.590		Quesnel	699.6	427.3	1,364.7	250	2,563
April 15	515,477				64.478		Cache Ck.	764.0	427.3	1,451.1	323	2,886
April 17	515,808	Y						764.0	427.3	1,451.1	331	3,217
	515,815		Y		83.261	374.9	Adams	847.3	802.2	1,937.6	7	3,224
	516,183				85.478	82.9	Adams	932.8	885.1	2,135.0	368	3,592
April 18	516,508	Y						932.8	885.1	2,135.0	325	3,917
	516,520		Y		98.002		Cache Ck.	1,030.8	885.1	2,266.3	12	3,929
April 19	516,863	Y						1,030.8	885.1	2,266.3	343	4,272
	516,928		Y		94.308		Cache Ck.	1,125.1	885.1	2,392.7	65	4,337
April 21	517,261				95.721	280.1	Adams	1,220.8	1165.2	2,801.1	333	4,670
(odom out	517,524	Y						1,220.8	1165.2	2,801.1	305	4,975
-multiply	517,548		Y		97.722		Cache Ck.	1,318.5	1165.2	2,932.0	28	5,003
by 1.16)	517,828				95.596		Quesnel	1,414.1	1165.2	3,060.1	325	5,328
April 22	518,051				75.968		Quesnel	1,490.1	1165.2	3,161.9	259	5,586
	518,330				69.256		Cache Ck.	1,559.3	1165.2	3,254.7	324	5,910
April 25	518,622				82.468	359.9	Adams	1,641.8	1525.1	3,725.1	339	6,249
	518,844				84.584		Merritt	1,726.4	1525.1	3,838.5	258	6,506
April 26	519,185				85.896		Merritt	1,812.3	1525.1	3,953.6	396	6,902
	519,408				99.921	210.5	Adams	1,912.2	1735.6	4,298.0	259	7,161
May 8	519,627				80.596	67.6	Adams	1,992.8	1803.2	4,473.6	254	7,415
May 9	519,918				91.512		Cache Ck.	2,084.3	1803.2	4,596.2	338	7,752
	520,201				82.980		Quesnel	2,167.3	1803.2	4,707.4	328	8,080
May 10	520,407				56.620		Quesnel	2,223.9	1803.2	4,783.3	239	8,319
	520,686				52.010		Cache Ck.	2,275.9	1803.2	4,852.9	324	8,643
	520,838				37.832		Merritt	2,313.8	1803.2	4,903.6	176	8,819
	520,945					335.3	Flood	2,313.8	2138.5	5,238.9	124	8,943
	521,060	odom. adjusted to						2,313.8	2138.5	5,238.9	133	9,077
	522,464							2,313.8	2138.5	5,238.9		9,077
May 11	522,471			12	88.349		Adams	2,402.1	2138.5	5,357.3	7	9,084
	522,578			6	28.473		Adams	2,430.6	2138.5	5,395.5	107	9,191
	522,578			3		65	Adams	2,430.6	2203.5	5,460.5		9,191
May 12	522,914			35	87.450		Cache Ck.	2,518.0	2203.5	5,577.7	336	9,527
	523,244			22	88.188		Quesnel	2,606.2	2203.5	5,695.8	330	9,857
May 13	523,488			12	61.228		Quesnel	2,667.4	2203.5	5,777.9	244	10,101
	523,811			25	57.562		Cache Ck.	2,725.0	2203.5	5,855.0	323	10,424
May 15	524,146			6		348.7	Adams	2,725.0	2552.2	6,203.7	335	10,759

TABLE D-1: FIRST QUARTER NATURAL GAS/DIESEL MONITORING DATA, SAFEWAY TRUCK B121

DATE (1989)	ODOMETER READING km	SWITCHED TO: DIESEL	SWITCHED TO: NAT.GAS	FILL TIME mins.	FUEL TAKEN ON: NAT.GAS kg	FUEL TAKEN ON: DIESEL litres	LOCATION	CUMULATIVE DATA (Since filling at 512,591 km) 1 kg gas = 1.34 litres diesel FUEL USE: NAT.GAS kg	FUEL USE: DIESEL litres	TOTAL DIESEL EQUIV. litres	DISTANCE BETWEEN DOMETER READINGS km	CUMUL. DISTANCE TRAVELLED km
	524,146			15	67.956		Adams	2,793.0	2552.2	6,294.8		10,759
	524,371			3		5. 3	Adams	2,793.0	2610.5	6,353.1	225	10,984
	524,371			22	61.556		Adams	2,854.5	2610.5	6,435.6		10,984
May 16	524,706			25	95.982		Cache Ck.	2,950.5	2610.5	6,564.2	335	11,319
	525,032			20	93.019		Quesnel	3,043.5	2610.5	6,688.8	326	11,645
May 17	525,271			25	61.372		Quesnel	3,104.9	2610.5	6,771.1	239	11,884
	525,595			25	57.012		Cache Ck.	3,161.9	2610.5	6,847.5	324	12,208
May 18	525,928			6		335.8	Adams	3,161.9	2946.3	7,183.3	333	12,541
	525,928			11	6 .417		Adams	3,231.3	2946.3	7,276.3		12,541
	526,019			3		46.7	Adams	3,231.3	2993.0	7,323.0	91	12,632
	526,019			12	42.072		Adams	3,273.4	2993.0	7,379.4		12,632
May 19	526,352	Y						3,273.4	2993.0	7,379.4	333	12,965
	526,356		Y	25	85.6		Cache Ck.	3,359.0	2993.0	7,494.1	4	12,969
	526,671	Y						3,359.0	2993.0	7,494.1	315	13,284
	526,687		Y	30	96.9		Quesnel	3,455.9	2993.0	7,623.9	16	13,300
	527,092	Y						3,455.9	2993.0	7,623.9	405	13,705
May 20	527,222					220.2	Sea Bird	3,455.9	3213.2	7,844.1	130	13,835
May 24	527,344		Y		105.947	124.8	Adams	3,561.8	3338.0	8,110.9	122	13,957
	527,602				73.652		Merritt	3,635.5	3338.0	8,209.6	258	14,215
	527,762				70.854		Cache Ck.	3,706.4	3338.0	8,304.5	160	14,375
May 25	528,080	Y						3,706.4	3338.0	8,304.5	318	14,693
	528,170		Y		83.7		Cache Ck.	3,790.1	3338.0	8,416.7	90	14,783
	528,505	Thermostats changed										
May 31	528,528	Y						3,790.1	3338.0	8,416.7	358	15,141
	528,546		Y					3,790.1	3338.0	8,416.7	18	15,159
	528,581			18	87.822		Adams	3,877.9	3338.0	8,534.3	35	15,194
	528,581			12		313.6	Adams	3,877.9	3651.6	8,847.9		15,194
June 5	528,955	Y						3,877.9	3651.6	8,847.9	374	15,568
	529,052			6		165	Bby. yard	3,877.9	3816.6	9,012.9	97	15,665
June 7	529,877					391	Lac LaHache	3,877.9	4207.6	9,403.9	825	16,490
June 8	530,442							3,877.9	4207.6	9,403.9	565	17,055
	530,452		Y	24	96.84		Adams	3,974.7	4207.6	9,533.7	10	17,065
	530,452			7		239.9	Adams	3,974.7	4447.5	9,773.6		17,065
June 9	530,815	Y						3,974.7	4447.5	9,773.6	363	17,428
	530,880		Y		91.518		Cache Ck.	4,066.2	4447.5	9,896.2	65	17,493
	531,190	Y						4,066.2	4447.5	9,896.2	310	17,803
	531,204		Y		86.082		Quesnel	4,152.3	4447.5	10,011.6	14	17,817
June 10	531,455				53.528		Quesnel	4,205.8	4447.5	10,083.3	251	18,068
	531,777				69.366		Cache Ck.	4,275.2	4447.5	10,176.3	322	18,390
June 11	532,112			12	68.969		Adams	4,344.2	4447.5	10,268.7	335	18,725
	532,112			6		403	Adams	4,344.2	4850.3	10,671.7		18,725
June 21	532,434			8	79.758		Adams	4,423.9	4850.5	10,778.6	322	19,047
June 22	532,691			14	78.02		Adams	4,502.0	4850.5	10,883.1	257	19,304
	532,691			4		169	Adams	4,502.0	5019.5	11,052.1		19,304
June 23	533,014	Y						4,502.0	5019.5	11,052.1	323	19,627
	533,039		Y		82.05		Cache Ck.	4,584.0	5019.5	11,162.1	25	19,652
	533,326	Y						4,584.0	5019.5	11,162.1	287	19,939
	533,371		Y		92.094		Quesnel	4,676.1	5019.5	11,285.5	45	19,984
June 24	533,618				59.306		Quesnel	4,735.4	5019.5	11,364.9	247	20,231
	533,944				59.148		Cache Ck.	4,794.6	5019.5	11,444.2	326	20,557
June 26	534,281			7		368	Adams	4,794.6	5387.5	11,812.2	337	20,894
	534,281			14	77.951		Adams	4,872.5	5387.5	11,916.7		20,894
	534,487			4		57.3	Adams	4,872.5	5444.8	11,974.0	206	21,100

TABLE D-1: FIRST QUARTER NATURAL GAS/DIESEL MONITORING DATA, SAFEWAY TRUCK B121

CUMULATIVE DATA (Since filling at 512,591 km)
1 kg gas = 1.34 litres diesel

DATE (1989)	ODOMETER READING km	SWITCHED TO: DIESEL	SWITCHED TO: NAT.GAS	FILL TIME mins.	FUEL TAKEN ON: NAT.GAS kg	FUEL TAKEN ON: DIESEL litres	LOCATION	FUEL USE: NAT.GAS kg	FUEL USE: DIESEL litres	TOTAL DIESEL EQUIV. litres	DISTANCE BETWEEN DOMETER READINGS km	CUMUL. DISTANCE TRAVELLED km
	534,487			12	63.09		Adams	4,935.6	5444.8	12,058.5		21,100
June 29	534,561			8	16.4		Adams	4,952.0	5444.8	12,080.5	74	21,174
July 3	534,800	Y		4		98.9	Bby. yard	4,952.0	5543.7	12,179.4	239	21,413
July 4	535,275					260	Lac LaHache	4,952.0	5803.7	12,439.4	475	21,888
July 5	535,870					265	Lac LaHache	4,952.0	6068.7	12,704.4	595	22,483
July 6	536,490			6		267	Adams	4,952.0	6335.7	12,971.4	620	23,103
July 6	536,584			2		43	Bby. yard	4,952.0	6378.7	13,014.4	94	23,197
July 11	537,636					516	Chilliwack	4,952.0	6894.7	13,530.4	1052	24,249
July 12	538,336					328.4	Pr. George	4,952.0	7223.1	13,858.8	700	24,949
July 12	539,100		Y		80.695	308.2	Adams	5,032.7	7531.3	14,275.1	764	25,713
Total Quarter					5,032.7	7,531.3		5,033	7,531	14,275	25713	

TABLE D-1: FIRST QUARTER NATURAL GAS/DIESEL MONITORING DATA, SAFEWAY TRUCK B121

	DISTANCE ON STRAIGHT DIESEL				CUMULATIVE DATA Excluding distance on straight diesel						
DATE (1989)	ODOMETER READING km	Between switches km	Cum. km	Cum.diesel use at 2.16 km/litre	FUEL USE: NAT.GAS kg	DIESEL litres	TOTAL DIESEL EQUIV. litres	CUMULATIVE DISTANCE TRAVELLED km	TOTAL FUEL USE: km/l	mpg	% GAS USE
April 6	512,591										
April 7	512,600										
	512,821				74		99	230	2.32	6.55	100%
	512,962				74	90	189	371	1.96	5.54	52%
April 10	512,962				74	90	189	371	1.96	5.54	52%
	513,189				74	90	189	598	3.16	8.93	52%
April 11	513,209				74	90	189	618	3.27	9.23	52%
	513,216	7	7	3	173	87	318	618	1.94	5.48	73%
	513,478		7	3	237	87	404	880	2.18	6.15	79%
April 12	513,820		7	3	237	87	404	1,222	3.02	8.54	79%
	513,889	69	76	35	322	350	781	1,222	1.56	4.41	55%
April 13	514,144		76	35	322	350	781	1,477	1.89	5.34	55%
April 13	514,152	8	84	39	397	346	879	1,477	1.68	4.75	61%
April 13	514,238		84	39	428	388	962	1,563	1.63	4.59	60%
April 14	514,560		84	39	428	388	962	1,885	1.96	5.53	60%
	514,577	17	101	47	526	381	1,085	1,885	1.74	4.90	65%
	514,904		101	47	621	381	1,213	2,212	1.82	5.15	69%
	515,154		101	47	700	381	1,318	2,462	1.87	5.27	71%
April 15	515,477		101	47	764	381	1,404	2,785	1.98	5.60	73%
April 17	515,808		101	47	764	381	1,404	3,116	2.22	6.26	73%
	515,815	7	108	50	847	752	1,888	3,116	1.65	4.66	60%
	516,183		108	50	933	835	2,085	3,484	1.67	4.72	60%
April 18	516,508		108	50	933	835	2,085	3,809	1.83	5.16	60%
	516,520	12	120	56	1,031	830	2,211	3,809	1.72	4.86	62%
April 19	516,863		120	56	1,031	830	2,211	4,152	1.88	5.30	62%
	516,928	65	185	86	1,125	799	2,307	4,152	1.80	5.08	65%
April 21	517,261		185	86	1,221	1,080	2,715	4,485	1.65	4.66	60%
(odom out	517,524		185	86	1,221	1,080	2,715	4,790	1.76	4.98	60%
-multiply	517,548	28	213	99	1,319	1,067	2,834	4,790	1.69	4.77	62%
by 1.16)	517,828		213	99	1,414	1,067	2,962	5,115	1.73	4.88	64%
April 22	518,051		213	99	1,490	1,067	3,063	5,374	1.75	4.95	65%
	518,330		213	99	1,559	1,067	3,156	5,697	1.81	5.10	66%
April 25	518,622		213	99	1,642	1,427	3,627	6,036	1.66	4.70	61%
	518,844		213	99	1,726	1,427	3,740	6,293	1.68	4.75	62%
April 26	519,185		213	99	1,812	1,427	3,855	6,689	1.74	4.90	63%
	519,408		213	99	1,912	1,637	4,199	6,948	1.65	4.67	61%
May 8	519,627		213	99	1,993	1,705	4,375	7,202	1.65	4.65	61%
May 9	519,918		213	99	2,084	1,705	4,498	7,539	1.68	4.73	62%
	520,201		213	99	2,167	1,705	4,609	7,868	1.71	4.82	63%
May 10	520,407		213	99	2,224	1,705	4,685	8,107	1.73	4.89	64%
	520,686		213	99	2,276	1,705	4,754	8,430	1.77	5.01	64%
	520,838		213	99	2,314	1,705	4,805	8,606	1.79	5.06	65%
	520,945		213	99	2,314	2,040	5,140	8,731	1.70	4.79	60%
	521,060		213	99	2,314	2,040	5,140	8,864	1.72	4.87	60%
	522,464		213	99	2,314	2,040	5,140	8,864	1.72	4.87	60%
May 11	522,471		213	99	2,402	2,040	5,259	8,871	1.69	4.76	61%
	522,578		213	99	2,431	2,040	5,297	8,978	1.69	4.78	61%
	522,578		213	99	2,431	2,105	5,362	8,978	1.67	4.73	61%
May 12	522,914		213	99	2,518	2,105	5,479	9,314	1.70	4.80	62%
	523,244		213	99	2,606	2,105	5,597	9,644	1.72	4.86	62%
May 13	523,488		213	99	2,667	2,105	5,679	9,888	1.74	4.92	63%
	523,811		213	99	2,725	2,105	5,757	10,211	1.77	5.01	63%
May 15	524,146		213	99	2,725	2,454	6,105	10,546	1.73	4.88	60%
	524,146		213	99	2,793	2,454	6,196	10,546	1.70	4.80	60%

TABLE D-1: FIRST QUARTER NATURAL GAS/DIESEL MONITORING DATA, SAFEWAY TRUCK B121

	DISTANCE ON STRAIGHT DIESEL				CUMULATIVE DATA Excluding distance on straight diesel						
DATE	ODOMETER READING	Between switches	Cum.	Cum.diesel use at 2.16	FUEL USE: NAT.GAS	DIESEL	TOTAL DIESEL EQUIV.	CUMULATIVE DISTANCE TRAVELLED	TOTAL FUEL USE:		% GAS
(1989)	km	km	km	km/litre	kg	litres	litres	km	km/l	mpg	USE
	524,371		213	99	2,793	2,512	6,255	10,771	1.72	4.86	60%
	524,371		213	99	2,855	2,512	6,337	10,771	1.70	4.80	60%
May 16	524,706		213	99	2,951	2,512	6,466	11,106	1.72	4.85	61%
	525,032		213	99	3,044	2,512	6,590	11,432	1.73	4.90	62%
May 17	525,271		213	99	3,105	2,512	6,673	11,671	1.75	4.94	62%
	525,595		213	99	3,162	2,512	6,749	11,995	1.78	5.02	63%
May 18	525,928		213	99	3,162	2,848	7,085	12,328	1.74	4.91	60%
	525,928		213	99	3,231	2,848	7,178	12,328	1.72	4.85	60%
	526,019		213	99	3,231	2,894	7,224	12,419	1.72	4.85	60%
	526,019		213	99	3,273	2,894	7,281	12,419	1.71	4.82	60%
May 19	526,352		213	99	3,273	2,894	7,281	12,752	1.75	4.94	60%
	526,356	4	217	100	3,359	2,893	7,394	12,752	1.72	4.87	61%
	526,671		217	100	3,359	2,893	7,394	13,067	1.77	4.99	61%
	526,687	16	233	108	3,456	2,885	7,516	13,067	1.74	4.91	62%
	527,092		233	108	3,456	2,885	7,516	13,472	1.79	5.06	62%
May 20	527,222		233	108	3,456	3,105	7,736	13,602	1.76	4.96	60%
May 24	527,344	252	485	224	3,562	3,114	7,886	13,472	1.71	4.82	61%
	527,602		485	224	3,635	3,114	7,985	13,730	1.72	4.85	61%
	527,762		485	224	3,706	3,114	8,080	13,890	1.72	4.85	61%
May 25	528,080		485	224	3,706	3,114	8,080	14,208	1.76	4.96	61%
	528,170	90	575	266	3,790	3,072	8,151	14,208	1.74	4.92	62%
	528,505		575	266							
May 31	528,528		575	266	3,790	3,072	8,151	14,566	1.79	5.05	62%
	528,546	18	593	274	3,790	3,064	8,142	14,566	1.79	5.05	62%
	528,581		593	274	3,878	3,064	8,260	14,601	1.77	4.99	63%
	528,581		593	274	3,878	3,377	8,574	14,601	1.70	4.81	61%
June 5	528,955		593	274	3,878	3,377	8,574	14,975	1.75	4.93	61%
	529,052	97	690	319	3,878	3,497	8,694	14,975	1.72	4.86	60%
June 7	529,877		1515	710	3,878	3,497	8,694	14,975	1.72	4.86	60%
June 8	530,442		2080	710	3,878	3,497	8,694	14,975	1.72	4.86	60%
	530,452	1400	2090	710	3,975	3,497	8,823	14,975	1.70	4.79	60%
	530,452		2090	950	3,975	3,497	8,823	14,975	1.70	4.79	60%
June 9	530,815		2090	950	3,975	3,497	8,823	15,338	1.74	4.91	60%
	530,880	65	2155	980	4,066	3,467	8,916	15,338	1.72	4.86	61%
	531,190		2155	980	4,066	3,467	8,916	15,648	1.76	4.95	61%
	531,204	14	2169	987	4,152	3,461	9,025	15,648	1.73	4.89	62%
June 10	531,455		2169	987	4,206	3,461	9,097	15,899	1.75	4.93	62%
	531,777		2169	987	4,275	3,461	9,190	16,221	1.77	4.98	62%
June 11	532,112		2169	987	4,344	3,461	9,282	16,556	1.78	5.04	63%
	532,112		2169	987	4,344	3,864	9,685	16,556	1.71	4.83	60%
June 21	532,434		2169	987	4,424	3,864	9,792	16,878	1.72	4.87	61%
June 22	532,691		2169	987	4,502	3,864	9,896	17,135	1.73	4.89	61%
	532,691		2169	987	4,502	4,033	10,065	17,135	1.70	4.81	60%
June 23	533,014		2169	987	4,502	4,033	10,065	17,458	1.73	4.90	60%
	533,039	25	2194	998	4,584	4,021	10,164	17,458	1.72	4.85	60%
	533,326		2194	998	4,584	4,021	10,164	17,745	1.75	4.93	60%
	533,371	45	2239	1019	4,676	4,000	10,266	17,745	1.73	4.88	61%
June 24	533,618		2239	1019	4,735	4,000	10,346	17,992	1.74	4.91	61%
	533,944		2239	1019	4,795	4,000	10,425	18,318	1.76	4.96	62%
June 26	534,281		2239	1019	4,795	4,368	10,793	18,655	1.73	4.88	60%
	534,281		2239	1019	4,873	4,368	10,898	18,655	1.71	4.83	60%
	534,487		2239	1019	4,873	4,426	10,955	18,861	1.72	4.86	60%
	534,487		2239	1019	4,936	4,426	11,039	18,861	1.71	4.82	60%
June 29	534,561		2239	1019	4,952	4,426	11,061	18,935	1.71	4.83	60%

TABLE D-1: FIRST QUARTER NATURAL GAS/DIESEL MONITORING DATA, SAFEWAY TRUCK B121

DATE (1989)	ODOMETER READING km	DISTANCE ON STRAIGHT DIESEL: Between switches km	DISTANCE ON STRAIGHT DIESEL: Cum. km	DISTANCE ON STRAIGHT DIESEL: Cum. diesel use at 2.16 km/litre	CUMULATIVE DATA (Excluding distance on straight diesel): FUEL USE: NAT.GAS kg	FUEL USE: DIESEL litres	TOTAL DIESEL EQUIV. litres	CUMULATIVE DISTANCE TRAVELLED km	TOTAL FUEL USE: km/l	TOTAL FUEL USE: mpg	% GAS USE
July 3	534,800		2239	1019	4,952	4,525	11,160	19,174	1.72	4.85	59%
July 4	535,275		2714	1279	4,952	4,525	11,160	19,174	1.72	4.85	59%
July 5	535,870		3309	1544	4,952	4,525	11,160	19,174	1.72	4.85	59%
July 6	536,490		3929	1811	4,952	4,525	11,160	19,174	1.72	4.85	59%
July 6	536,584		4023	1854	4,952	4,525	11,160	19,174	1.72	4.85	59%
July 11	537,636		5075	2370	4,952	4,525	11,160	19,174	1.72	4.85	59%
July 12	538,336		5775	2699	4,952	4,525	11,160	19,174	1.72	4.85	59%
July 12	539,100	4300	6539	3007	5,033	4,525	11,268	19,174	1.70	4.80	60%
Total Quarter		6539	6539	3007	5033	4525	11268	19174	1.70	4.80	60%

TABLE D-2: SECOND QUARTER NATURAL GAS/DIESEL MONITORING DATA, SAFEWAY TRUCK B121

								CUMULATIVE DATA (Since filling at 512.591 km) 1 kg gas = 1.34 litres diesel				
DATE	ODOMETER READING km	SWITCHED TO: DIESEL	SWITCHED TO: NAT.GAS	FILL TIME mins.	FUEL TAKEN ON: NAT.GAS kg	FUEL TAKEN ON: DIESEL litres	LOCATION	FUEL USE: NAT.GAS kg	DIESEL litres	TOTAL DIESEL EQUIV. litres	DISTANCE BETWEEN ODOMETER READINGS km	CUMUL. DISTANCE TRAVELLED km
July 12	539,100		Y		80.695	308.2	Adams	5,032.7	7531.3	14,275.1	764	25,713
July 15	539,400	Y					Merritt	5,032.7	7531.3	14,275.1	300	26,013
July 17	539,809		Y	6		237	Adams	5,032.7	7768.3	14,512.1	409	26,422
	539,809			24	93.435		Adams	5,126.1	7768.3	14,637.3		26,422
July 18	540,056			4		74.5	Adams	5,126.1	7842.8	14,711.8	247	26,669
	540,056			37	75.065		Adams	5,201.2	7842.8	14,812.4		26,669
July 18	540,337			20	88.164		Cache Ck.	5,289.4	7842.8	14,930.5	281	26,950
	540,704	Y						5,289.4	7842.8	14,930.5	367	27,317
July 19	541,277	Problem with gas		10		367.3	Cache Ck.	5,289.4	8210.1	15,297.8	573	27,890
July 21	541,725		Y	6		211.2	Adams	5,289.4	8421.3	15,509.0	448	28,338
	541,725			10	100		Adams	5,389.4	8421.3	15,643.0		28,338
July 25	542,066	Y						5,389.4	8421.3	15,643.0	341	28,679
	542,073		Y	25	91.51		Cache Ck.	5,480.9	8421.3	15,765.7	7	28,686
	542,370	Y						5,480.9	8421.3	15,765.7	297	28,983
	542,399		Y	25	87.366		Quesnel	5,568.2	8421.3	15,882.7	29	29,012
July 26	542,525	Y				208.2	Pr. George	5,568.2	8629.5	16,090.9	126	29,138
July 28	543,304		Y	20	39.53	302.1	Adams	5,607.8	8931.6	16,446.0	779	29,917
	543,561			17	63.876		Merritt	5,671.6	8931.6	16,531.6	257	30,174
	543,782			37	77.926		Vernon	5,749.6	8931.6	16,636.0	221	30,395
July 29	543,984			10	35.944		Merritt	5,785.5	8931.6	16,684.2	202	30,597
July 31	544,250			6		209.2	Adams	5,785.5	9140.8	16,893.4	266	30,863
	544,250			6	54.246		Adams	5,839.7	9140.8	16,966.1		30,863
Aug 1	544,476			35	74.764	68.2	Adams	5,914.5	9209.0	17,134.4	226	31,089
	544,807			27	77.626		Cache Ck.	5,992.1	9209.0	17,238.5	331	31,420
	545,101	Y						5,992.1	9209.0	17,238.5	294	31,714
	545,134		Y	23	100.96		Quesnel	6,093.1	9209.0	17,373.8	33	31,747
Aug 2	545,378	System problems,		17	37.828		Quesnel	6,130.9	9209.0	17,424.4	244	31,991
	545,702	124 km diesel (e)		20	44.456		Cache Ck.	6,175.4	9209.0	17,484.0	324	32,315
	545,789	Y						6,175.4	9209.0	17,484.0	87	32,402
	546,050					467.1	Chilliwack	6,175.4	9676.1	17,951.1	261	32,663
Aug 4	546,145		Y	20	17.164		Adams	6,192.5	9676.1	17,974.1	95	32,758
	546,403			15	45.372		Merritt	6,237.9	9676.1	18,034.9	258	33,016
	546,685	Y						6,237.9	9676.1	18,034.9	282	33,298
	546,728		Y	20	89.744		Penticton	6,327.7	9676.1	18,155.2	43	33,341
Aug 5	547,028			27	98.254		Chilliwack	6,425.9	9676.1	18,286.8	300	33,641
Aug 15	547,125			40	40.848	299.3	Adams	6,466.8	9975.4	18,640.9	97	33,738
	547,457			23	80.35		Cache Ck.	6,547.1	9975.4	18,748.5	332	34,070
Aug 16	547,783			22	97.95		Quesnel	6,645.1	9975.4	18,879.8	326	34,396
	548,024			13	54.15		Quesnel	6,699.2	9975.4	18,952.3	241	34,637
	548,348			27	58.438		Cache Ck.	6,757.7	9975.4	19,030.7	324	34,961
Aug 18	548,707			42	78.815	350.7	Adams	6,836.5	10326.1	19,487.0	359	35,320
	548,826	Y						6,836.5	10326.1	19,487.0	119	35,439
	548,850		Y					6,836.5	10326.1	19,487.0	24	35,463
	548,865	Y						6,836.5	10326.1	19,487.0	15	35,478
Aug 19	548,956		Y					6,836.5	10326.1	19,487.0	91	35,569
	548,996	Y						6,836.5	10326.1	19,487.0	40	35,609
	549,536					372.6	Kamloops	6,836.5	10698.7	19,859.6	540	36,149
Aug 22	549,905		Y		42.63	140	Adams	6,879.1	10838.7	20,056.7	369	36,518
Aug 24	550,213	125 km diesel (e)			50.108		Merritt	6,929.2	10838.7	20,123.8	308	36,826
Aug 25	550,425				47.22		Merritt	6,976.4	10838.7	20,187.1	212	37,038
Aug 29	550,757			12	75.168		Adams	7,051.6	10838.7	20,287.8	332	37,370
	550,757			6		258	Adams	7,051.6	11096.7	20,545.8		37,370
Aug 31	551,019	65 km diesel (e)		12	74.239		Adams	7,125.8	11096.7	20,645.3	262	37,632

TABLE D-2: SECOND QUARTER NATURAL GAS/DIESEL MONITORING DATA, SAFEWAY TRUCK B121

								CUMULATIVE DATA (Since filling at 512.591 km) 1 kg gas = 1.34 litres diesel				
DATE	ODOMETER READING km	SWITCHED TO: DIESEL	SWITCHED TO: NAT.GAS	FILL TIME mins.	FUEL TAKEN ON: NAT.GAS kg	FUEL TAKEN ON: DIESEL litres	LOCATION	FUEL USE: NAT.GAS kg	DIESEL litres	TOTAL DIESEL EQUIV. litres	DISTANCE BETWEEN ODOMETER READINGS km	CUMUL. DISTANCE TRAVELLED km
Sept 6	551,382	Y						7,125.8	11096.7	20,645.3	363	37,995
	551,454			5		216.7	Bby. yard	7,125.8	11313.4	20,862.0	72	38,067
Sept 7	551,594		Y					7,125.8	11313.4	20,862.0	140	38,207
	551,602			12	77.447		Adams	7,203.3	11313.4	20,965.8	8	38,215
Sept 11	551,915			11	80.881		Adams	7,284.2	11313.4	21,074.2	313	38,528
Sept 13	552,228			10	68.908		Adams	7,353.1	11313.4	21,166.5	313	38,841
	552,228			5		263.7	Adams	7,353.1	11577.1	21,430.2		38,841
Sept 19	552,490	Y						7,353.1	11577.1	21,430.2	262	39,103
	552,928		Y					7,353.1	11577.1	21,430.2	438	39,541
	552,936			12	78.438		Adams	7,431.5	11577.1	21,535.3	8	39,549
	552,936			7		303.7	Adams	7,431.5	11880.8	21,839.0		39,549
Sept 20	553,080			10	35.801		Adams	7,467.3	11880.8	21,887.0	144	39,693
Sept 26	553,080	Y						7,467.3	11880.8	21,887.0		39,693
	553,346		Y		24.543	184.9	Adams	7,491.9	12065.7	22,104.8	266	39,959
Sept 27	553,580	Y	System malfunction					7,491.9	12065.7	22,104.8	234	40,193
	554,133			10		317.5	Pr.George	7,491.9	12383.2	22,422.3	553	40,746
Oct 4	554,898		Y					7,491.9	12383.2	22,422.3	765	41,511
	554,927			9	59.688		Adams	7,551.5	12383.2	22,502.3	29	41,540
Oct 5	555,174			10	66.726		Adams	7,618.3	12383.2	22,591.7	247	41,787
	555,174			6		379.7	Adams	7,618.3	12762.9	22,971.4		41,787
TOTAL SECOND QUARTER	16,074				2,585.6	5,231.6		2,585.6	5,231.6	8,696.3	16,074	16,074

TABLE D-2: SECOND QUARTER NATURAL GAS/DIESEL MONITORING DATA, SAFEWAY TRUCK B121

		DISTANCE ON STRAIGHT DIESEL			CUMULATIVE DATA Excluding distance on straight diesel						
DATE	ODOMETER READING km	Between switches km	Cum. km	Cum.diesel use at 2.16 km/litre (litres)	FUEL USE: NAT.GAS kg	DIESEL litres	TOTAL DIESEL EQUIV. litres	CUMULATIVE DISTANCE TRAVELLED km	TOTAL FUEL USE: km/l	mpg	% GAS USE
July 12	539,100	4300	6539	3007	5,033	4,525	11,268	19,174	1.70	4.80	60%
July 15	539,400		6539	3007	5,033	4,525	11,268	19,474	1.73	4.88	60%
July 17	539,809	409	6948	3196	5,033	4,572	11,316	19,474	1.72	4.86	60%
	539,809		6948	3196	5,126	4,572	11,441	19,474	1.70	4.81	60%
July 18	540,056		6948	3196	5,126	4,647	11,516	19,721	1.71	4.83	60%
	540,056		6948	3196	5,201	4,647	11,616	19,721	1.70	4.79	60%
July 18	540,337		6948	3196	5,289	4,647	11,735	20,002	1.70	4.81	60%
	540,704		6948	3196	5,289	4,647	11,735	20,369	1.74	4.90	60%
July 19	541,277		6948	3196	5,289	5,014	12,102	20,942	1.73	4.89	59%
July 21	541,725	1021	7969	3669	5,289	4,753	11,841	20,369	1.72	4.86	60%
	541,725		7969	3669	5,389	4,753	11,975	20,369	1.70	4.80	60%
July 25	542,066		7969	3669	5,389	4,753	11,975	20,710	1.73	4.88	60%
	542,073	7	7976	3672	5,481	4,750	12,094	20,710	1.71	4.83	61%
	542,370		7976	3672	5,481	4,750	12,094	21,007	1.74	4.90	61%
	542,399	29	8005	3685	5,568	4,736	12,198	21,007	1.72	4.86	61%
July 26	542,525		8005	3685	5,568	4,944	12,406	21,133	1.70	4.81	60%
July 28	543,304	779	8784	4046	5,608	4,886	12,400	21,133	1.70	4.81	61%
	543,561		8784	4046	5,672	4,886	12,486	21,390	1.71	4.84	61%
	543,782		8784	4046	5,750	4,886	12,590	21,611	1.72	4.85	61%
July 29	543,984		8784	4046	5,786	4,886	12,638	21,813	1.73	4.87	61%
July 31	544,250		8784	4046	5,786	5,095	12,848	22,079	1.72	4.85	60%
	544,250		8784	4046	5,840	5,095	12,920	22,079	1.71	4.82	61%
Aug 1	544,476		8784	4046	5,915	5,163	13,089	22,305	1.70	4.81	61%
	544,807		8784	4046	5,992	5,163	13,193	22,636	1.72	4.84	61%
	545,101		8784	4046	5,992	5,163	13,193	22,930	1.74	4.91	61%
	545,134	33	8817	4061	6,093	5,148	13,313	22,930	1.72	4.86	61%
Aug 2	545,378		8817	4061	6,131	5,148	13,363	23,174	1.73	4.90	61%
	545,702	124	8941	4118	6,175	5,091	13,366	23,374	1.75	4.94	62%
	545,789		8941	4118	6,175	5,091	13,366	23,461	1.76	4.96	62%
	546,050		8941	4118	6,175	5,558	13,833	23,722	1.71	4.84	60%
Aug 4	546,145	356	9297	4283	6,193	5,393	13,691	23,461	1.71	4.84	61%
	546,403		9297	4283	6,238	5,393	13,752	23,719	1.72	4.87	61%
	546,685		9297	4283	6,238	5,393	13,752	24,001	1.75	4.93	61%
	546,728	43	9340	4303	6,328	5,373	13,852	24,001	1.73	4.89	61%
Aug 5	547,028		9340	4303	6,426	5,373	13,984	24,301	1.74	4.91	62%
Aug 15	547,125		9340	4303	6,467	5,672	14,338	24,398	1.70	4.80	60%
	547,457		9340	4303	6,547	5,672	14,446	24,730	1.71	4.83	61%
Aug 16	547,783		9340	4303	6,645	5,672	14,577	25,056	1.72	4.85	61%
	548,024		9340	4303	6,699	5,672	14,649	25,297	1.73	4.87	61%
	548,348		9340	4303	6,758	5,672	14,728	25,621	1.74	4.91	61%
Aug 18	548,707		9340	4303	6,836	6,023	15,184	25,980	1.71	4.83	60%
	548,826		9340	4303	6,836	6,023	15,184	26,099	1.72	4.85	60%
	548,850	24	9364	4314	6,836	6,012	15,173	26,099	1.72	4.86	60%
	548,865		9364	4314	6,836	6,012	15,173	26,114	1.72	4.86	60%
Aug 19	548,956	91	9455	4356	6,836	5,970	15,131	26,114	1.73	4.87	61%
	548,996		9455	4356	6,836	5,970	15,131	26,154	1.73	4.88	61%
	549,536		9455	4356	6,836	6,342	15,503	26,694	1.72	4.86	59%
Aug 22	549,905	909	10364	4777	6,879	6,062	15,280	26,154	1.71	4.83	60%
Aug 24	550,213	125	10489	4835	6,929	6,004	15,289	26,337	1.72	4.86	61%
Aug 25	550,425		10489	4835	6,976	6,004	15,352	26,549	1.73	4.88	61%
Aug 29	550,757		10489	4835	7,052	6,004	15,453	26,881	1.74	4.91	61%
	550,757		10489	4835	7,052	6,262	15,711	26,881	1.71	4.83	60%
Aug 31	551,019	65	10554	4865	7,126	6,232	15,780	27,078	1.72	4.84	61%

TABLE D-2: SECOND QUARTER NATURAL GAS/DIESEL MONITORING DATA, SAFEWAY TRUCK B121

	DISTANCE ON STRAIGHT DIESEL				CUMULATIVE DATA Excluding distance on straight diesel						
DATE	ODOMETER READING km	Between switches km	Cum. km	Cum diesel use at 2.16 km/litre (litres)	FUEL USE: NAT.GAS kg	DIESEL litres	TOTAL DIESEL EQUIV. litres	CUMULATIVE DISTANCE TRAVELLED km	TOTAL FUEL USE: km/l	mpg	% GAS USE
Sept 6	551,382		10554	4865	7,126	6,232	15,780	27,441	1.74	4.91	61%
	551,454		10554	4865	7,126	6,449	15,997	27,513	1.72	4.86	60%
Sept 7	551,594	212	10766	4963	7,126	6,350	15,899	27,441	1.73	4.87	60%
	551,602		10766	4963	7,203	6,350	16,003	27,449	1.72	4.84	60%
Sept 11	551,915		10766	4963	7,284	6,350	16,111	27,762	1.72	4.86	61%
Sept 13	552,228		10766	4963	7,353	6,350	16,204	28,075	1.73	4.89	61%
	552,228		10766	4963	7,353	6,614	16,467	28,075	1.70	4.81	60%
Sept 19	552,490		10766	4963	7,353	6,614	16,467	28,337	1.72	4.86	60%
	552,928	438	11204	5166	7,353	6,411	16,265	28,337	1.74	4.92	61%
	552,936		11204	5166	7,432	6,411	16,370	28,345	1.73	4.89	61%
	552,936		11204	5166	7,432	6,715	16,673	28,345	1.70	4.80	60%
Sept 20	553,080		11204	5166	7,467	6,715	16,721	28,489	1.70	4.81	60%
Sept 26	553,080		11204	5166	7,467	6,715	16,721	28,489	1.70	4.81	60%
	553,346	266	11470	5289	7,492	6,777	16,816	28,489	1.69	4.78	60%
Sept 27	553,580		11470	5289	7,492	6,777	16,816	28,723	1.71	4.82	60%
	554,133		11470	5289	7,492	7,094	17,134	29,276	1.71	4.82	59%
Oct 4	554,898	1318	12788	5899	7,492	6,484	16,524	28,723	1.74	4.91	61%
	554,927		12788	5899	7,552	6,484	16,604	28,752	1.73	4.89	61%
Oct 5	555,174		12788	5899	7,618	6,484	16,693	28,999	1.74	4.90	61%
	555,174		12788	5899	7,618	6,864	17,073	28,999	1.70	4.80	60%
TOTAL SECOND QUARTER	16,074	6249	6,249	2,892	2,586	2,340	5,804	9,825	1.69	4.78	60%

TABLE D-3: THIRD QUARTER NATURAL GAS/DIESEL MONITORING DATA, SAFEWAY TRUCK B121

CUMULATIVE DATA (Since filling at 512.591 km)
1 kg gas = 1.34 litres diesel

DATE	ODOMETER READING km	SWITCHED TO: DIESEL	SWITCHED TO: NAT.GAS	FILL TIME mins.	FUEL TAKEN ON: NAT.GAS kg	FUEL TAKEN ON: DIESEL litres	LOCATION	FUEL USE: NAT.GAS kg	DIESEL litres	TOTAL DIESEL EQUIV. litres	DISTANCE BETWEEN ODOMETER READINGS km	CUMUL DISTANCE TRAVELLED km
								7,618.3	12762.9	22,971.4		41,787
Oct 5	555,174											
Oct 12	555,390			20	66.698		Adams	7,685.0	12762.9	23,060.8	216	42,003
								7,685.0	12762.9	23,060.8	29	42,032
Oct 16	555,419	Y						7,685.0	13005.9	23,303.8	323	42,355
	555,742			6		243	Bby.yard	7,685.0	13005.9	23,303.8	8	42,363
Oct 17	555,750		Y					7,776.6	13005.9	23,426.5	328	42,691
	556,078			25	91.608		Cache Ck.	7,878.1	13005.9	23,562.5	451	43,142
Oct 18	556,529			25	101.5		Pr.George	7,878.1	13196.3	23,752.9	5	43,147
	556,534			10		190.4	Pr.George	7,989.5	13196.3	23,902.3	530	43,677
Oct 18	557,064				111.472		Kamloops	7,989.5	13196.3	23,902.3	338	44,015
	557,402	Y						7,989.5	13396.3	24,102.3	2	44,017
Oct 23	557,404			5		200	Bby.yard	7,989.5	13396.3	24,102.3	93	44,110
	557,497		Y					7,989.5	13396.3	24,102.3	4	44,114
	557,501	Y						7,989.5	13396.3	24,102.3	60	44,174
	557,561		Y					7,989.5	13396.3	24,102.3	14	44,188
	557,575	Y						7,989.5	13496.3	24,202.3	58	44,246
	557,633			4		100	Bby.yard	7,989.5	13861.3	24,567.3	779	45,025
Oct 24	558,412			5		365	Pr.George	7,989.5	14238.8	24,944.8	847	45,872
Oct 27	559,259			6		377.5	Bby.yard	7,989.5	14238.8	24,944.8	201	46,073
Oct 30	559,460		Y					8,072.2	14238.8	25,055.6	8	46,081
	559,468			12	82.696		Adams	8,072.2	14421.6	25,238.4	279	46,360
Oct 31	559,747			4		182.8	Adams	8,156.5	14421.6	25,351.4		46,360
	559,747			16	84.303		Adams	8,156.5	14496.0	25,425.8	243	46,603
Nov 2	559,990			3		74.4	Adams	8,228.8	14496.0	25,522.6		46,603
	559,990			16	72.276		Adams	8,228.8	14496.0	25,522.6	30	46,633
Nov 3	560,020							8,228.8	14496.0	25,522.6	331	46,964
	560,351	Y						8,326.5	14496.0	25,653.5	31	46,995
	560,382		Y	25	97.673		Penticton	8,404.4	14496.0	25,757.9	327	47,322
Nov 4	560,709			25	77.9		Merritt	8,404.4	14496.0	25,757.9	260	47,582
	560,969							8,404.4	14496.0	25,757.9	4	47,586
Nov 14	560,973	Y						8,404.4	14782.0	26,043.9	36	47,622
	561,009			6		286	Bby.yard	8,404.4	14991.0	26,252.9	413	48,035
Nov 16	561,422			5		209	Adams	8,404.4	15303.6	26,565.5	634	48,669
Nov 21	562,056		Y	5		312.6	Adams	8,485.8	15303.6	26,674.6		48,669
	562,056			14	81.414		Adams	8,485.8	15369.4	26,740.4	260	48,929
Nov 22	562,316			3		65.8	Adams	8,555.8	15369.4	26,834.2		48,929
	562,316			14	70.038		Adams	8,555.8	15369.4	26,834.2	365	49,294
Nov 29	562,681	Y						8,555.8	15585.4	27,050.2	246	49,540
	562,927			6		216	Bby.yard	8,555.8	15677.0	27,141.8	195	49,735
	563,122		Y	3		91.6	Adams	8,655.6	15677.0	27,275.5		49,735
	563,122			17	99.762		Adams	8,655.6	15677.0	27,275.5	278	50,013
Dec 1	563,400	Y (est)						8,655.6	15979.9	27,578.4	422	50,435
Dec 6	563,822			6		302.9	Bby.yard	8,655.6	16181.9	27,780.4	287	50,722
Dec 11	564,109			5		202	Bby.yard	8,655.6	16315.9	27,914.4	311	51,033
Dec 12	564,420		Y	3		134	Adams	8,738.7	16315.9	28,025.8		51,033
	564,420			16	83.1		Adams	8,738.7	16315.9	28,025.8	283	51,316
Dec 14	564,703	Y						8,738.7	16491.8	28,201.7	195	51,511
	564,898		Y	4		175.9	Adams	8,830.8	16491.8	28,325.0		51,511
	564,898			16	92.047		Adams	8,926.4	16491.8	28,453.2	362	51,873
Dec 19	565,260	(e)			95.656		Adams	8,983.7	16692.6	28,730.7	217	52,090
Dec 22	565,477			20	57.275	200.8	Adams					
TOTAL THIRD QUARTER	10,303				1,365.4	3,929.7		1,365.4	3,929.7	5,759.4	10,303	10,303

TABLE D-3: THIRD QUARTER NATURAL GAS/DIESEL MONITORING DATA, SAFEWAY TRUCK B121

	DISTANCE ON STRAIGHT DIESEL				CUMULATIVE DATA Excluding distance on straight diesel						
DATE	ODOMETER READING km	Between switches km	Cum. km	Cum.diesel use at 2.03 km/litre	FUEL USE: NAT.GAS kg	DIESEL litres	TOTAL DIESEL EQUIV. litres	CUMULATIVE DISTANCE TRAVELLED km	TOTAL FUEL USE km/l	TOTAL FUEL USE mpg	% GAS USE
Oct 5	555,174		12788	5899	7,618	6,864	17,072	28,999	1.70	4.80	60%
Oct 12	555,390		12788	5899	7,685	6,864	17,162	29,215	1.70	4.81	60%
Oct 16	555,419		12788	5899	7,685	6,864	17,162	29,244	1.70	4.81	60%
	555,742		12788	5899	7,685	7,107	17,405	29,567	1.70	4.80	59%
Oct 17	555,750	331	13119	6062	7,685	6,944	17,242	29,244	1.70	4.79	60%
	556,078		13119	6062	7,777	6,944	17,365	29,572	1.70	4.81	60%
Oct 18	556,529		13119	6062	7,878	6,944	17,501	30,023	1.72	4.84	60%
	556,534		13119	6062	7,878	7,135	17,691	30,028	1.70	4.79	60%
Oct 18	557,064		13119	6062	7,990	7,135	17,841	30,558	1.71	4.84	60%
	557,402		13119	6062	7,990	7,135	17,841	30,896	1.73	4.89	60%
Oct 23	557,404		13119	6062	7,990	7,335	18,041	30,898	1.71	4.84	59%
	557,497	95	13214	6108	7,990	7,288	17,994	30,896	1.72	4.85	59%
	557,501		13214	6108	7,990	7,288	17,994	30,900	1.72	4.85	59%
	557,561	60	13274	6138	7,990	7,259	17,965	30,900	1.72	4.86	60%
	557,575		13274	6138	7,990	7,259	17,965	30,914	1.72	4.86	60%
	557,633		13274	6138	7,990	7,359	18,065	30,972	1.71	4.84	59%
Oct 24	558,412		13274	6138	7,990	7,724	18,430	31,751	1.72	4.86	58%
Oct 27	559,259		13274	6138	7,990	8,101	18,807	32,598	1.73	4.89	57%
Oct 30	559,460	1885	15159	7065	7,990	7,174	17,880	30,914	1.73	4.88	60%
	559,468		15159	7065	8,072	7,174	17,991	30,922	1.72	4.85	60%
Oct 31	559,747		15159	7065	8,072	7,357	18,174	31,201	1.72	4.85	60%
	559,747		15159	7065	8,157	7,357	18,287	31,201	1.71	4.82	60%
Nov 2	559,990		15159	7065	8,157	7,431	18,361	31,444	1.71	4.83	60%
	559,990		15159	7065	8,229	7,431	18,458	31,444	1.70	4.81	60%
Nov 3	560,020		15159	7065	8,229	7,431	18,458	31,474	1.71	4.81	60%
	560,351		15159	7065	8,229	7,431	18,458	31,805	1.72	4.86	60%
	560,382	31	15190	7080	8,326	7,416	18,573	31,805	1.71	4.83	60%
Nov 4	560,709		15190	7080	8,404	7,416	18,678	32,132	1.72	4.86	60%
	560,969		15190	7080	8,404	7,416	18,678	32,392	1.73	4.90	60%
Nov 14	560,973		15190	7080	8,404	7,416	18,678	32,396	1.73	4.90	60%
	561,009		15190	7080	8,404	7,702	18,964	32,432	1.71	4.83	59%
Nov 16	561,422		15190	7080	8,404	7,911	19,173	32,845	1.71	4.84	59%
Nov 21	562,056	1083	16273	7613	8,404	7,691	18,953	32,396	1.71	4.83	59%
	562,056		16273	7613	8,486	7,691	19,062	32,396	1.70	4.80	60%
Nov 22	562,316		16273	7613	8,486	7,757	19,128	32,656	1.71	4.82	59%
	562,316		16273	7613	8,556	7,757	19,221	32,656	1.70	4.80	60%
Nov 29	562,681		16273	7613	8,556	7,757	19,221	33,021	1.72	4.85	60%
	562,927		16273	7613	8,556	7,973	19,437	33,267	1.71	4.83	59%
	563,122	441	16714	7830	8,556	7,847	19,312	33,021	1.71	4.83	59%
	563,122		16714	7830	8,656	7,847	19,446	33,021	1.70	4.79	60%
Dec 1	563,400		16714	7830	8,656	7,847	19,446	33,299	1.71	4.83	60%
Dec 6	563,822		16714	7830	8,656	8,150	19,749	33,721	1.71	4.82	59%
Dec 11	564,109		16714	7830	8,656	8,352	19,951	34,008	1.70	4.81	58%
Dec 12	564,420	1020	17734	8331	8,656	7,985	19,583	33,299	1.70	4.80	59%
	564,420		17734	8331	8,739	7,985	19,694	33,299	1.69	4.77	59%
Dec 14	564,703		17734	8331	8,739	7,985	19,694	33,582	1.71	4.81	59%
	564,898	195	17929	8427	8,739	8,065	19,774	33,582	1.70	4.79	59%
	564,898		17929	8427	8,831	8,065	19,898	33,582	1.69	4.76	59%
Dec 19	565,260		17929	8427	8,926	8,065	20,026	33,944	1.69	4.79	60%
Dec 22	565,477		17929	8427	8,984	8,265	20,304	34,161	1.68	4.75	59%
TOTAL THIRD QUARTER	10,303	5,141	5,141	2,528	1,365	1,402	3,231	5,162	1.60	4.51	57%

TABLE D-4: FOURTH QUARTER NATURAL GAS/DIESEL MONITORING DATA, SAFEWAY TRUCK B121

DATE	ODOMETER READING km	SWITCHED TO: DIESEL	SWITCHED TO: NAT.GAS	FILL TIME mins.	FUEL TAKEN ON: NAT.GAS kg	FUEL TAKEN ON: DIESEL litres	LOCATION	CUMULATIVE DATA (Since filling at 512,591 km) 1 kg gas = 1.34 litres diesel FUEL USE: NAT.GAS kg	FUEL USE: DIESEL litres	TOTAL DIESEL EQUIV. litres	DISTANCE BETWEEN ODOMETER READINGS km	CUMUL. DISTANCE TRAVELLED km
								8,983.7	16692.6	28,730.7		52,090
Dec 22	565,477							8,983.7	16692.6	28,730.7	186	52,276
	565,663	Y						8,983.7	16958.6	28,996.8	446	52,722
Jan 4	566,109					266	Osoyoos	8,983.7	17158.6	29,196.8	482	53,204
Jan 5	566,591					200	Osoyoos	8,983.7	17301.9	29,340.1	252	53,456
Jan 5	566,843					143.3	Flood	9,062.8	17385.4	29,529.5	140	53,596
Jan 9	566,983				79.056	83.5	Adams	9,062.8	17385.4	29,529.5	4	53,600
	566,987		Y					9,062.8	17385.4	29,529.5	299	53,899
	567,286	Y						9,159.9	17385.4	29,659.6	28	53,927
	567,314			25	97.102		Cache Ck.	9,159.9	17385.4	29,659.6	2	53,929
	567,316		Y					9,258.8	17385.4	29,792.2	325	54,254
	567,641			35	98.968		Quesnel	9,258.8	17574.5	29,981.3	140	54,394
Jan 10	567,781					189.1	Pr.George	9,320.0	17574.5	30,063.3	113	54,507
	567,894			20	61.166		Quesnel	9,391.6	17574.5	30,159.2	325	54,832
	568,219			25	71.58		Cache Ck.	9,391.6	17743.2	30,327.9	332	55,164
Jan 12	568,551	Y (e)				168.7	Bby yard	9,455.2	17743.2	30,413.2	329	55,493
	568,880			25	63.65		Cache Ck.	9,455.2	17743.2	30,413.2	5	55,498
	568,885		Y					9,513.3	17743.2	30,491.1	254	55,752
Jan 13	569,139			15	58.108		Kelowna	9,513.3	17743.2	30,491.1	163	55,915
	569,302	Y						9,585.1	18203.4	31,047.4	427	56,342
Jan 15	569,729		Y (e)		71.729	460.2	Adams	9,585.1	18203.4	31,047.4	282	56,624
	570,011	Y (e)						9,688.3	18470.6	31,452.9	256	56,880
Feb 9	570,267				103.258	267.2	Adams	9,688.3	18470.6	31,452.9	4	56,884
	570,271		Y					9,688.3	18470.6	31,452.9	300	57,184
	570,571	Y						9,786.9	18470.6	31,585.0	28	57,212
	570,599			20	98.58		Cache Ck.	9,786.9	18470.6	31,585.0	3	57,215
	570,602		Y					9,786.9	18600.6	31,715.0	203	57,418
	570,805					130	Wms. Lake	9,786.9	18600.6	31,715.0	167	57,585
	570,972	Y						9,892.2	18600.6	31,856.1	38	57,623
Feb 10	571,010			35	105.27		Cache Ck.	9,892.2	18600.6	31,856.1	5	57,628
	571,015		Y					9,892.2	18600.6	31,856.1	324	57,952
	571,339	Y						9,980.2	18600.6	31,974.1	11	57,963
Feb 20	571,350		Y (e)	15	88.072		Adams	9,980.2	18726.6	32,100.1		57,963
	571,350			6		126	Adams	9,980.2	18726.6	32,100.1	196	58,159
	571,546	Y (e)						10,046.0	18903.5	32,365.1	190	58,349
Feb 26	571,736				65.721	176.9	Adams	10,046.0	18903.5	32,365.1	27	58,376
Feb 27	571,763		Y					10,046.0	18903.5	32,365.1	284	58,660
	572,047	Y						10,136.0	18903.5	32,485.8	27	58,687
	572,074			20	90.068		Cache Ck.	10,136.0	18903.5	32,485.8	2	58,689
	572,076		Y					10,243.8	18903.5	32,630.2	325	59,014
Feb 28	572,401			30	107.8		Quesnel	10,243.8	19107.2	32,833.9	127	59,141
	572,528			8		203.7	Pr. George	10,296.5	19107.2	32,904.5	114	59,255
	572,642			20	52.668		Quesnel	10,296.5	19107.2	32,904.5	501	59,756
	573,143	Y						10,397.9	19365.8	33,299.0	276	60,032
Mar 1	573,419				101.4	258.6	Adams	10,397.9	19365.8	33,299.0	8	60,040
	573,427		Y					10,397.9	19365.8	33,299.0	40	60,080
Mar 2	573,467	Y						10,397.9	19365.8	33,299.0	223	60,303
	573,690		Y					10,397.9	19365.8	33,299.0	196	60,499
	573,886	Y (e)						10,397.9	19653.8	33,587.0	184	60,683
Mar 9	574,070			6		288	Bby yard	10,397.9	19813.5	33,746.7	295	60,978
Mar 12	574,365			4		159.7	Adams	10,465.8	19813.5	33,837.6		60,978
	574,365		Y (e)	9	67.885		Adams	10,465.8	19813.5	33,837.6	274	61,252
	574,639	Y (e)						10,555.1	20035.5	34,179.3	234	61,486
Mar 20	574,873			30	89.3	222	Adams	10,555.1	20035.5	34,179.3	3	61,489
	574,876		Y									

TABLE D-4: FOURTH QUARTER NATURAL GAS/DIESEL MONITORING DATA, SAFEWAY TRUCK B121

CUMULATIVE DATA (Since filling at 512.591 km)
1 kg gas = 1.34 litres diesel

DATE	ODOMETER READING km	SWITCHED TO: DIESEL	SWITCHED TO: NAT.GAS	FILL TIME mins.	FUEL TAKEN ON: NAT.GAS kg	FUEL TAKEN ON: DIESEL litres	LOCATION	FUEL USE: NAT.GAS kg	FUEL USE: DIESEL litres	TOTAL DIESEL EQUIV. litres	DISTANCE BETWEEN ODOMETER READINGS km	CUMUL. DISTANCE TRAVELLED km
	575,204			20	82.59		Cache Ck.	10,637.7	20035.5	34,290.0	328	61,817
Mar 21	575,533			30	112.738		Quesnel	10,750.4	20035.5	34,441.0	329	62,146
	575,647					173.6	Pr. George	10,750.4	20209.1	34,614.6	114	62,260
	575,773			15	52.736		Quesnel	10,803.1	20209.1	34,685.3	126	62,386
Mar 22	576,098			30	59.602		Cache Ck.	10,862.7	20209.1	34,765.2	325	62,711
	576,432	Y			58.273	163.9	Adams	10,921.0	20373.0	35,007.2	334	63,045
Mar 23	576,464		Y					10,921.0	20373.0	35,007.2	32	63,077
	576,729	Y						10,921.0	20373.0	35,007.2	265	63,342
	576,787		Y	30	111.296		Kamloops	11,032.3	20373.0	35,156.3	58	63,400
	577,192	Y						11,032.3	20373.0	35,156.3	405	63,805
April 4	577,390				61.037	302.6	Adams	11,093.4	20675.6	35,540.7	198	64,003
TOTAL FOURTH QUARTER	11,913				2,109.7	3,983.0		2,109.7	3,983.0	6,810.0	11,913	11,913

TABLE D-4: FOURTH QUARTER NATURAL GAS/DIESEL MONITORING DATA, SAFEWAY TRUCK B121

	DISTANCE ON STRAIGHT DIESEL				CUMULATIVE DATA Excluding distance on straight diesel						
DATE	ODOMETER READING km	Between switches km	Cum. km	Cum.diesel use at 1.99 km/litre	FUEL USE: NAT.GAS kg	DIESEL litres	TOTAL DIESEL EQUIV. litres	CUMULATIVE DISTANCE TRAVELLED km	TOTAL FUEL USE: km/l	mpg	% GAS USE
Dec 22	565,477		17929	8427	8,984	8,265	20,304	34,161	1.68	4.75	59%
	565,663		17929	8427	8,984	8,266	20,304	34,347	1.69	4.78	59%
Jan 4	566,109		17929	8427	8,984	8,532	20,570	34,793	1.69	4.78	59%
Jan 5	566,591		17929	8427	8,984	8,732	20,770	35,275	1.70	4.79	58%
Jan 5	566,843		17929	8427	8,984	8,875	20,913	35,527	1.70	4.80	58%
Jan 9	566,983		17929	8427	9,063	8,958	21,102	35,667	1.69	4.77	58%
	566,987	1324	19253	9091	9,063	8,294	20,438	34,347	1.68	4.74	59%
	567,286		19253	9091	9,063	8,294	20,438	34,646	1.70	4.79	59%
	567,314		19253	9091	9,160	8,294	20,568	34,674	1.69	4.76	60%
	567,316	30	19283	9106	9,160	8,279	20,553	34,646	1.69	4.76	60%
	567,641		19283	9106	9,259	8,279	20,686	34,971	1.69	4.77	60%
Jan 10	567,781		19283	9106	9,259	8,468	20,875	35,111	1.68	4.75	59%
	567,894		19283	9106	9,320	8,468	20,957	35,224	1.68	4.74	60%
	568,219		19283	9106	9,392	8,468	21,053	35,549	1.69	4.77	60%
Jan 12	568,551		19283	9106	9,392	8,637	21,222	35,881	1.69	4.77	59%
	568,880		19283	9106	9,455	8,637	21,307	36,210	1.70	4.80	59%
	568,885	334	19617	9274	9,455	8,469	21,139	35,881	1.70	4.79	60%
Jan 13	569,139		19617	9274	9,513	8,469	21,217	36,135	1.70	4.81	60%
	569,302		19617	9274	9,513	8,469	21,217	36,298	1.71	4.83	60%
Jan 15	569,729	427	20044	9488	9,585	8,715	21,559	36,298	1.68	4.75	60%
	570,011		20044	9488	9,585	8,715	21,559	36,580	1.70	4.79	60%
Feb 9	570,267		20044	9488	9,688	8,982	21,965	36,836	1.68	4.73	59%
	570,271	260	20304	9619	9,688	8,852	21,834	36,580	1.68	4.73	59%
	570,571		20304	9619	9,688	8,852	21,834	36,880	1.69	4.77	59%
	570,599		20304	9619	9,787	8,852	21,966	36,908	1.68	4.74	60%
	570,602	31	20335	9634	9,787	8,836	21,951	36,880	1.68	4.74	60%
	570,805		20335	9634	9,787	8,966	22,081	37,083	1.68	4.74	59%
	570,972		20335	9634	9,787	8,966	22,081	37,250	1.69	4.76	59%
Feb 10	571,010		20335	9634	9,892	8,966	22,222	37,288	1.68	4.74	60%
	571,015	43	20378	9656	9,892	8,945	22,200	37,250	1.68	4.74	60%
	571,339		20378	9656	9,892	8,945	22,200	37,574	1.69	4.78	60%
Feb 20	571,350	11	20389	9661	9,980	8,939	22,313	37,574	1.68	4.75	60%
	571,350		20389	9661	9,980	9,065	22,439	37,574	1.67	4.73	60%
	571,546		20389	9661	9,980	9,065	22,439	37,770	1.68	4.75	60%
Feb 26	571,736		20389	9661	10,046	9,242	22,704	37,960	1.67	4.72	59%
Feb 27	571,763	217	20606	9770	10,046	9,133	22,595	37,770	1.67	4.72	60%
	572,047		20606	9770	10,046	9,133	22,595	38,054	1.68	4.75	60%
	572,074		20606	9770	10,136	9,133	22,716	38,081	1.68	4.73	60%
	572,076	29	20635	9785	10,136	9,119	22,701	38,054	1.68	4.73	60%
Feb 28	572,401		20635	9785	10,244	9,119	22,846	38,379	1.68	4.74	60%
	572,528		20635	9785	10,244	9,323	23,049	38,506	1.67	4.72	60%
	572,642		20635	9785	10,296	9,323	23,120	38,620	1.67	4.72	60%
	573,143		20635	9785	10,296	9,323	23,120	39,121	1.69	4.78	60%
Mar 1	573,419		20635	9785	10,398	9,581	23,514	39,397	1.68	4.73	59%
	573,427	284	20919	9927	10,398	9,439	23,372	39,121	1.67	4.73	60%
Mar 2	573,467		20919	9927	10,398	9,439	23,372	39,161	1.68	4.73	60%
	573,690	223	21142	10039	10,398	9,327	23,260	39,161	1.68	4.75	60%
	573,886		21142	10039	10,398	9,327	23,260	39,357	1.69	4.78	60%
Mar 9	574,070		21142	10039	10,398	9,615	23,548	39,541	1.68	4.74	59%
Mar 12	574,365	479	21621	10279	10,398	9,534	23,467	39,357	1.68	4.73	59%
	574,365		21621	10279	10,466	9,534	23,558	39,357	1.67	4.72	60%
	574,639		21621	10279	10,466	9,534	23,558	39,631	1.68	4.75	60%
Mar 20	574,873		21621	10279	10,555	9,756	23,900	39,865	1.67	4.71	59%
	574,876	237	21858	10398	10,555	9,637	23,781	39,631	1.67	4.70	59%

TABLE D-4: FOURTH QUARTER NATURAL GAS/DIESEL MONITORING DATA, SAFEWAY TRUCK B121

	DISTANCE ON STRAIGHT DIESEL				CUMULATIVE DATA Excluding distance on straight diesel						
DATE	ODOMETER READING km	Between switches km	Cum. km	Cum. diesel use at 1.99 km/litre	FUEL USE: NAT.GAS kg	DIESEL litres	TOTAL DIESEL EQUIV. litres	CUMULATIVE DISTANCE TRAVELLED km	TOTAL FUEL USE: km/l	mpg	% GAS USE
	575,204		21858	10398	10,638	9,637	23,892	39,959	1.67	4.72	60%
Mar 21	575,533		21858	10398	10,750	9,637	24,043	40,288	1.68	4.73	60%
	575,647		21858	10398	10,750	9,811	24,216	40,402	1.67	4.71	59%
	575,773		21858	10398	10,803	9,811	24,287	40,528	1.67	4.71	60%
Mar 22	576,098		21858	10398	10,863	9,811	24,367	40,853	1.68	4.73	60%
	576,432		21858	10398	10,921	9,975	24,609	41,187	1.67	4.72	59%
Mar 23	576,464	32	21890	10414	10,921	9,959	24,593	41,187	1.67	4.73	60%
	576,729		21890	10414	10,921	9,959	24,593	41,452	1.69	4.76	60%
	576,787	58	21948	10443	11,032	9,930	24,713	41,452	1.68	4.74	60%
	577,192		21948	10443	11,032	9,930	24,713	41,857	1.69	4.78	60%
April 4	577,390	198	22146	10543	11,093	10,133	24,998	41,857	1.67	4.73	59%
TOTAL FOURTH QUARTER	11,913	4217	4217	2116	2,110	1,867	4,694	7,696	1.64	4.63	60%

APPENDIX E

NATURAL GAS AND DIESEL FUEL

ENERGY EQUIVALENCY AND EFFICIENCY DATA

APPENDIX E

NATURAL GAS AND DIESEL FUEL ENERGY EQUIVALENCY AND EFFICIENCY DATA

In order to calculate the relative thermal efficiency of the Safeway demonstration truck on dual fuel natural gas diesel versus straight diesel, it was necessary to establish the heating values of the diesel fuel and natural gas consumed by the truck. There is considerable variation in the heating value of natural gas in different regions, while a substantial seasonal variation also exists in the heating value of summer versus winter grade diesel fuels. The project team therefore sought heating value data that pertained specifically to the natural gas and diesel fuel consumed by the truck. This information is summarized in Table E-1.

In establishing an equivalency between diesel fuel and natural gas, the lower heating value (LHV) is used as it provides a measure of the net amount of heat available to do useful work. This is in contrast to the higher heating value (HHV) which is a measure of the gross amount of heat before deducting the latent heat of the amount of water vapour produced from the hydrogen content of the fuel. Since the water vapour in the products of combustion is not condensed in the engine, the latent heat of vapourization is not available to perform useful work.

B.C. Gas supplied monthly average natural gas quality data for the period of the demonstration (April 1989 to March 1990). The specific gravity of the gas (relative to air) was 0.580, while the HHV was 38.69 MJ/m3. Given that the weight of air is about 1.2250 kg/m3, the natural gas had a HHV of 54.43 MJ/kg. This translates into a LHV of 49.06 MJ/kg, based upon the ratio of LHV/HHV calculated for a typical gas composition in the B.C. Gas service area.

Chevron, the supplier of nearly all the diesel fuel used in this demonstration, provided data on the higher heating value and API gravity of the main grades of diesel fuel used during the course of the project. Most of the fuel used was summer grade diesel with a HHV of 39.29 MJ/litre and API Gravity of 31.1. This translates into a LHV of about 36.93 MJ/litre, based on the relationship between API Gravity and LHV/HHV ratios derived from ASME Power Test Codes.

This grade of diesel fuel would be used from the end of March until October. At that time, trucks hauling in the Lower Mainland of B.C. (the area between Vancouver and Hope, B.C.) would switch to a slightly lower pour (-20 degrees C) winter grade diesel, while those hauling to the Interior would use the minus 40 pour grade. Between October and March, the Safeway truck used both the Interior and Lower Mainland grades of winter diesel fuel, depending where it refuelled.

On the basis of the data shown in Table E-1, one kilogram of natural gas would be equal to about 1.33 litres of both the summer and winter grades of diesel fuel used by the truck in the Lower Mainland, and to about 1.37 litres of the Interior winter grade fuel. Interior winter grade fuel was only taken on by the truck when it was refuelled at the Safeway yard in Burnaby or at Interior locations during the months from October to March. Based on a compilation of the volumes of fuel taken on at these locations during the third and fourth quarters of the monitoring period, it is estimated that Interior winter grade diesel fuel accounted for about 20 percent of total diesel consumption. For the purposes of calculating average comparative fuel efficiency during the monitoring period, a coefficient of 1.34 litres of diesel fuel per kilogram of natural gas has been used, reflecting the dominant use of the Lower Mainland grades of diesel fuel.

Tables E-2 and E-3 show how trip-by-trip fuel consumption data for highway and local duty cycles, respectively, were used to calculate relative fuel efficiency for the Safeway truck on dual fuel natural gas/diesel versus straight diesel operation. Table E-4 compares the fuel efficiency of the truck when loaded and hauling uphill to the Interior with that of its return trips when it was empty and generally going downhill.

TABLE E-1: NATURAL GAS AND DIESEL FUEL ENERGY EQUIVALENCY DATA

NATURAL GAS QUALITY DATA, B.C GAS SERVICE AREA

YEAR	MONTH	SPECIFIC GRAVITY	MJ/m3	MJ/kg* HHV	MJ/kg** LHV
1989	April	0.580	38.66	54.41	49.02
	May	0.581	38.80	54.52	49.11
	June	0.583	38.89	54.45	49.06
	July	0.577	38.44	54.38	49.00
	Aug	0.579	38.52	54.31	48.93
	Sept	0.581	38.76	54.46	49.06
	Oct	0.580	38.69	54.45	49.06
	Nov	0.579	38.67	54.52	49.12
	Dec	0.581	38.72	54.40	49.01
	Jan	0.580	38.66	54.41	49.02
	Feb	0.582	38.70	54.28	48.90
	Mar	0.580	38.80	54.61	49.20
	AVG	0.580	38.69	54.43	49.04

* Based on air density of 1.225 kg/m3.
** Based on LHV/HHV ratio of 0.9009
LHV = lower heating value; HHV = higher heating value.

LHV/HHV RATIO OF PRINCIPAL NATURAL GAS COMPONENTS

COMPONENT	% TOTAL	LHV/ HHV	WEIGHTED LHV/ HHV*
Methane	95.50%	90.04%	86.86%
Ethane	3.00%	91.47%	2.77%
Propane	0.50%	92.00%	0.46%
TOTAL	99.00%		90.09%

* Re-weighted as a percentage of the total of the three principal constituents. The remaining one percent of natural gas is primarily nitrogen and carbon dioxide, which have no heating value.

CHEVRON DIESEL FUEL QUALITY

	Pour Point 'C	API Gravity	HHV Btu/gal	HHV kJ/litre	LHV/ HHV	LHV kJ/litre
LOWER MAINLAND:						
Summer grade	-17	31.1	169,300	39,290	0.940	36,932
Winter grade	-20	31.8	168,800	39,174	0.940	36,823
INTERIOR:						
Winter grade	-40	37.9	164,400	38,153	0.938	35,787

NATURAL GAS/DIESEL EQUIVALENCY FACTORS

(litres of diesel per kg of natural gas at equal thermal efficiency)

	HHV	LHV
LOWER MAINLAND:		
Summer grade	1.385	1.32[illegible]
Winter grade	1.390	1.332
INTERIOR:		
Winter grade	1.427	1.370

TABLE E-2: FUEL EFFICIENCY ON HIGHWAY TRIPS, DUAL FUEL vs. STRAIGHT DIESEL

DUAL FUEL

	NATURAL GAS		DIESEL	TOTAL		DISTANCE	FUEL EFFICIENCY	
Quarter 1	kg	lde	litres	lde*	% gas	km	km/lde	mpg
June 9 - 11	369.5	491.4	403.0	894.4	54.9%	1660	1.86	5.24
June 23 - 26	370.5	492.8	368.0	860.8	57.2%	1590	1.85	5.21
TOTAL	740.0	984.2	771.0	1755.2	56.1%	3250	1.85	5.23

* lde = litres diesel equivalent. For this period, one kilogram of natural gas is equal to 1.33 litres of Lower Mainland summer grade diesel fuel, based upon data from Table E-1.

STRAIGHT DIESEL

	DIESEL	DISTANCE	FUEL EFFICIENCY	
Quarter 1	litres metered	km	km/lde	km/lde
June 5 - 8	630.9	1400	2.22	6.26
July 3 - 12	1987.6	4300	2.16	6.11
TOTAL	2618.5	5700	2.18	6.15

FUEL EFFICIENCY ON LOCAL TRIPS, DUAL FUEL vs. STRAIGHT DIESEL

		km/lde	mpg
Dual fuel efficiency		1.85	5.23
Diesel fuel efficiency		2.18	6.15
Increase in energy use per km on dual fuel	17.56%		
Decrease in thermal efficiency on dual fuel	14.94%		

TABLE E-3: FUEL EFFICIENCY ON LOCAL TRIPS, DUAL FUEL vs. STRAIGHT DIESEL

DUAL FUEL

Quarter 1	NATURAL GAS kg	lde	DIESEL litres	TOTAL lde	% gas	DISTANCE km	FUEL EFFICIENCY km/lde	mpg
April 17	85.5	113.7	82.9	196.6	57.8%	368	1.87	5.28
May 8	80.6	107.2	67.6	174.8	61.3%	254	1.45	4.10
May 15	61.6	81.9	58.3	140.2	58.4%	225	1.60	4.53
June 22	157.8	209.9	169.0	378.9	55.4%	579	1.53	4.31
June 26	63.1	83.9	57.3	141.2	59.4%	206	1.46	4.12
TOTAL	448.6	596.6	435.1	1,031.7	57.8%	1632	1.58	4.47

* lde = litres diesel equivalent. For this period, one kilogram of natural gas is equal to 1.33 litres of Lower Mainland summer grade diesel fuel, based upon data from Table E-1.

STRAIGHT DIESEL

Quarter 3	DIESEL litres metered	DISTANCE km	FUEL EFFICIENCY km/lde	km/lde
Nov. 16	209.0	413	1.98	5.58
Nov. 21	312.6	634	2.03	5.73
Nov. 29	91.6	195	2.13	6.01
Dec. 11	202.0	287	1.42	4.01
Dec. 12	134.0	311	2.32	6.55
TOTAL*	949.2	1840	1.94	5.47
ADJUSTED TOTAL**	930.4	1840	1.98	5.58

* About 60 % of total diesel fuel consumed over this period was Interior winter grade, and the remaining 40 % Lower Mainland winter grade.

** Adjusted to summer grade equivalent on basis of foregoing proportions and lower heating values detailed in Table E-1.

FUEL EFFICIENCY ON LOCAL TRIPS, DUAL FUEL vs. STRAIGHT DIESEL

		km/lde	mpg
Dual fuel efficiency		1.58	4.47
Diesel fuel efficiency		1.98	5.58
Increase in energy use per km on dual fuel	25.02%		
Decrease in thermal efficiency on dual fuel	20.01%		

TABLE E-4: HIGHWAY FUEL USE TO AND FROM INTERIOR LOCATIONS

NATURAL GAS

QUARTER 1	FUEL USE TO INTERIOR			FUEL USE FROM INTERIOR				RATIO OF FUEL USE TO vs FROM INTERIOR
Date	NAT. GAS KG	KM	KM/KG	NAT. GAS KG	KM	KM/KG	DISTANCE BETWEEN:	
April 14	98.3	322	3.28	83.3	331	3.97	Burnaby - Cache Ck.	1.21
	95	327	3.44	64.5	323	5.01	Cache Ck. - Quesnel	1.45
Total	193.3	649	3.36	147.8	654	4.42	Total	1.32
April 21	97.7	305	3.12	82.5	339	4.11	Burnaby - Cache Ck.	1.32
	95.6	325	3.40	69.3	324	4.68	Cache Ck. - Quesnel	1.38
Total	193.3	630	3.26	151.8	663	4.37	Total	1.34
May 9	83	328	3.95	52	324	6.23	Cache Ck. - Quesnel	1.58
May 11	87.5	336	3.84	68	335	4.93	Burnaby - Cache Ck.	1.28
	88.2	330	3.74	57.7	323	5.60	Cache Ck. - Quesnel	1.50
Total	175.7	666	3.79	125.7	658	5.23	Total	1.38
May 16	96	335	3.49	69.4	333	4.80	Burnaby - Cache Ck.	1.38
	93	326	3.51	57	324	5.68	Cache Ck. - Quesnel	1.62
Total	189	661	3.50	126.4	657	5.20	Total	1.49
June 23	82.1	323	3.93	78	337	4.32	Burnaby - Cache Ck.	1.10
	92.1	287	3.12	59.1	326	5.52	Cache Ck. - Quesnel	1.77
Total	174.2	610	3.50	137.1	663	4.84	Total	1.38

STRAIGHT DIESEL FUEL

QUARTER 1	FUEL USE TO INTERIOR			FUEL USE FROM INTERIOR				
Date	DIESEL LITRES	KM	KM/L	DIESEL LITRES	KM	KM/L		
July 12	328.4	700	2.13	308.2	764	2.48	Burnaby - Prince George	1.16
Oct 24	365	779	2.13	377.5	877	2.32	Burnaby - Prince George	1.09

DUAL FUEL DIESEL

QUARTER 4	FUEL USE TO INTERIOR			FUEL USE FROM INTERIOR				
Date	DIESEL LITRES	KM	KM/L	DIESEL LITRES	KM	KM/L		
March 21	173.6	774	4.46	163.9	785	4.79	Burnaby - Prince George	1.07

APPENDIX F

PROMOTIONAL ACTIVITIES UNDERTAKEN DURING ADAMS NATURAL GAS/DIESEL DEMONSTRATION PROJECT

APPENDIX F

PROMOTIONAL ACTIVITIES UNDERTAKEN DURING ADAMS NATURAL GAS/DIESEL DEMONSTRATION PROJECT

An important objective of the Adams project is to assist natural gas/diesel technology transfer through participation in promotional activities. During this time period the truck received considerable national and international publicity, as detailed in the following section.

1. Footage of the Safeway truck and Christie/Adams station was shot on June 29, 1989 and subsequently shown on the CBC "National" news, including interviews with the driver, Stan Murray, and John Adams. The context for the filming of the Adams project was the future role of alternative fuels in improving air quality.

2. The Federal Minister of Energy, Mines and Resources, The Honourable Jake Epp, visited the Christie/Adams station on July 21, 1989 to announce a natural gas/diesel demonstration involving B.C. Transit, and an extension of the NGV grant program in B.C. The Safeway truck was on hand for this event and the local driver, Stan Murray, briefed the Minister on the operation of the truck.

3. The Safeway truck was also featured in the July 1989 issue (No. 10, page 3) of the "Centre for Alternative Transportation Fuels Review" published by B.C. Research Corporation. This publication is distributed in many different countries around the world.

4. The Safeway Trucking Department produced a video of the truck for presentation at the Safeway Distribution meeting in Napa, California on September 25, 1989. Norm Engemoen, Trucking Department Manager of Safeway's British Columbia operations, and Joe Haddon of B.C. Gas attended this meeting. Considerable interest in the Safeway demonstration truck was shown by some of the large U.S. trucking companies in attendance.

5. The local driver, Stan Murray, has been very active in taking the truck to many of the secondary schools and other educational institutions in southwestern British Columbia and discussing the potential emissions benefits of natural gas use in heavy vehicle applications with the students. School visits to date include:

Nov 30/89	Howe Sound Secondary School, Squamish
Mar 15/90	Centennial Sr. Sec. School, Coquitlam
Apr 2/90	Centennial Sr. Sec. School, Coquitlam
Apr 3/90	Dr. Charles Best Jr. Sec. School, Coquitlam
Apr 4/90	Frank Hurt Sec. School, Surrey
Apr 5/90	Terry Fox Sr. Sec. School, Port Coquitlam
Apr 6/90	Brookswood Sec. School, Langley
Apr 9/90	Camosun College, Victoria
Apr 10/90	Belmont Sec. School, Victoria
Apr 10/90	Victoria Sec. School, Victoria
Apr 11/90	Esquimalt Sec. School, Victoria
Apr 11/90	Spectrum Sec. School, Victoria
Apr 21/90	Brookswood Sec. School, Langley. On display for "Earth Day" celebrations.

6. The Safeway truck has also been on display at various special events including:

   - the opening of the Pacific Traffic Education Centre at the Boundary Bay Airport in September 1989.

   - the Society of Automotive Engineers' seminar on alternative fuels at the British Columbia Institute of Technology on March 3, 1989.

7. In addition, there have been many visitors from other countries and provinces who were shown the Safeway truck and the Adams station during the course of the one-year demonstration period. It is estimated that in the order of 2,000 people have visited the station to date.

Such promotional activities contributed to the truck logging considerably less distance per week than during the first quarter, as it was kept around town for the various videotaping sessions and special events. However, these activities have greatly raised the profile of the Adams project, and have acted as an effective vehicle for natural gas/diesel technology transfer.

PART B

CENTURION FUEL SYSTEMS SPARK-IGNITION NATURAL GAS ENGINE DEMONSTRATION PROJECT

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ABSTRACT

This report presents a brief overview of the results of an independent project to demonstrate the technical and economic viability of using a monofuel, natural gas spark-ignition engine in heavy truck applications under commercial operating conditions. Centurion Fuel Systems of Fort St. John, British Columbia re-engined a 1977 Kenworth logging truck tractor with a Cummins NTC Big Cam II 400 HP power unit converted to spark-ignition natural gas operation in New Zealand. The truck has accumulated about 88,000 km since going into commercial service in February 1989. This report presents data on comparative fuel consumption of the natural gas engine versus the original diesel engine in the truck, along with specifications of the demonstration vehicle and main features of its operational experience.

Figure 1: Centurion Fuel Systems' Natural Gas Fuelled Demonstration Truck

CENTURION FUEL SYSTEMS
SPARK-IGNITION NATURAL GAS ENGINE
DEMONSTRATION PROJECT

1.0 BACKGROUND

Centurion Fuel Systems (formerly Tundra Turbos) of Fort St. John, B.C. has been involved with natural gas vehicles for the past 8 years, both as an installer and distributor of natural gas conversion system equipment. The company has also operated a natural gas fuelling station in Fort St. John since 1985.

In February 1989, Centurion Fuel Systems, in conjunction with ICG Utilities (British Columbia) Ltd., initiated an independent demonstration project involving a local logging truck which as re-powered by a natural gas fuelled, spark-ignition engine. The general goal of this project was to demonstrate the technical and economic feasibility of using a monofuel, natural gas spark-ignition engine in heavy truck applications. Specific objectives included refinement of the conversion technology, including engine brake, in preparation for ultimate manufacturing and marketing in Canada.

The Centurion truck has run in commercial service in the Fort St. John area for the past year, accumulating considerable operational experience. It therefore was decided that it would be useful to document the performance of this truck under funding from the John F. Adams Natural Gas/Diesel Demonstration Project. The objectives of Adams project are fully described in another report covering the performance of a dual fuel natural gas/diesel truck operated by Canada Safeway from April 1989 to April 1990.

Canadian Resourcecon verified and analyzed records of diesel fuel consumption of the Centurion truck prior to its conversion relative to natural gas consumption after its conversion. The remainder of the information in this report was provided by Centurion Fuel Systems.

2.0 CONVERSION OF ENGINE TO NATURAL GAS

A Cummins NTC Big Cam II 400 HP diesel engine was rebuilt, then shipped to New Zealand for conversion to spark-ignition natural gas operation by Transport Fuel Systems, a company with considerable experience in such conversions. Conversion of the engine to monofuel natural gas operation required a number of different modifications, as described in the following section.

Piston modifications: stock Cummins pistons were modified through machining to reduce the compression ratio of the engine to eliminate pre-ignition and improve the flame front.

Adaptation of cylinder heads: in order to install spark plugs, special tubes were added to the injector sleeve. This required boring out the cylinder heads where the injectors came through. In addition, the valves, valve seats, and valve guides were changed to a material more compatible with the higher exhaust temperatures associated with natural gas. The standard umbrella seal was replaced with a more positive seal to stop oil from reaching the combustion chamber.

Adaptation of engine compression brake: adaptation of the engine brake involved extensive modifications to the injector rocker, slave piston, and master piston. These modifications cannot be revealed as they are the subject of a current application for patent rights.

Addition of ignition pick-up: an ignition pick-up, supplied by Transport Fuel Systems of New Zealand, is mounted to the front camshaft bearing cap and driven directly off the camshaft.

Spark plug lead insulation sleeve: an insulated extension made of teflon is used to hold the spark plug wire and boot as it is inserted through the Jacobs head, rocker head, and into the cylinder head and onto the spark plug. A rubber cap then is placed over the top of the extension to seal it from foreign dirt, etc.

Spark plugs and leads: a 12 mm by 19 mm reach automotive style spark plug is used. It is also possible to use a 14 mm spark plug. For spark plug leads, high-quality leads of no less than 8 mm in diameter are used.

Cooling system: The aftercooler assembly was changed from the single pass standard cooler to a low-flow, triple pass aftercooler. This required that the radiator be changed from a full-flow type to a triple-pass, low-flow type, while the thermostat housing had to be changed to a double thermostat housing assembly for low-flow cooling.

Governor: The governor is a throttle body controlled by a pneumatic ram which, in turn, is governed by the ignition control box.

Natural gas fuelling system: two first-stage NZIG regulators in parallel are used to achieve initial high-pressure reduction of the natural gas. Two Impco Model E regulators are used as second stage, low-pressure regulators. An Impco model D 200 mixer is used with an Impco throttle body.

Turbocharger: a modified Cummins S.T. 50 type turbocharger with modifications to the turbine housing, compressor wheel, and compressor housing is used to increase turbo boost at low RPM. This boost is then directed through a balance line to the low pressure regulators to equalize the turbo boost pressure in the carburetor. The application of low engine RPM turbocharger boost to the engine is intended to achieve improved bottom end torque.

Turbocharger boost regulation: a bypass valve is situated in the air induction system between the turbocharger and the carburetor. This is a spring-loaded valve which senses turbo boost pressure and, after being set to the desired manifold pressure, will open up, relieving excess boost pressure and returning it to the air intake.

Ignition system: the ignition system is supplied by Transport Fuel Systems of New Zealand. It employs two solid state Hall-effect switches for timing and pilot signal sources, an electronic control box and six high-tension coils.

Knock sensor: a knock sensor is fitted into the engine block and connected to the ignition box. In the event of pre-ignition, the engine will emit an audible signal to warn the driver, and the timing will automatically retard until the pre-ignition has ceased.

Following these modifications, the engine was shipped back to Fort St. John, having achieved the following requirements specified by Centurion:

- equivalent or better torque and horsepower curves as the stock diesel engine;

- retention of the engine compression brake;

- ability to fit into a standard Class 8 truck with minimum or no modification to the truck underhood area.

3.0 CONVERSION OF DEMONSTRATION VEHICLE TO NATURAL GAS

3.1 Selection of Demonstration Vehicle

During conversion of the engine in New Zealand, a search was initiated to identify a suitable truck in the Fort St. John area in which to install the engine. The two main industries in this area involving heavy trucks are logging and oil field transportation. It was felt that a logging truck would be a better vehicle for conversion, as the route used by these vehicles requires a return to Fort St. John twice a day, which would enable the use of the present refuelling station operated by Centurion Fuel Systems.

A number of operators were approached, but few were willing to convert without costly downtime agreements even though the conversion offered the potential for substantial fuel savings. Ultimately, Peace Wood Products agreed to have one of its trucks re-engined with the natural gas engine developed for Centurion.

3.2 Description of Demonstration Vehicle

The unit chosen was a 1977 Kenworth tractor unit used to haul short-length logs on a 45-foot "hayrack"-style trailer with two sets of bunks. Unlike conventional logging trucks which piggyback their trailers when unloaded, this truck has a trailer which is too long to be piggybacked. This combination, which has a total of 5 axles, weighs about 16,800 kg empty, and in excess of 45,000 kg fully loaded during winter hauling conditions.

The original power unit in this truck was a 1977-vintage Detroit Diesel 8V-92T series engine rated at 430 HP. This engine was still mechanically sound when removed, although it was renowned for leaking oil and being rather noisy. The truck is equipped with a Fuller RTO 12513 transmission with SSHD 5.29:1 ratio rear axles yielding a top speed of 90 km/h at 2200 RPM.

3.3 Natural Gas Fuel System

The two original diesel tanks (545 litres per tank) on each side of the truck were removed. Four Aluswiss 128-litre water capacity aluminum gas storage cylinders were then mounted between the cab and the rear wheels on each side, as shown in Figure 1. In addition, four 52-litre water capacity CNG Cylinder Corporation aluminum cylinders were mounted under the right-side step. Total natural gas storage thus is 1232 litres water capacity. Based upon observed monitoring results, as discussed in Section 5.2, this volume of fuel storage gives the truck a range of about 400 km on its normal log haul route.

A natural gas cylinder mounting frame was made of 4 by 4 by 3/16 inch square tubing fastened to the truck frame with 1/2 inch bolts. Steel bands were used to secure the cylinders to the frame. Centurion Fuel Systems reports that the natural gas fuel storage system increased the net weight of the truck by about 400 kg compared to before conversion when it had two full diesel tanks. Details of the weight of diesel equipment removed versus natural gas equipment added, however, are not available on a separate basis. Instead, the approach was to weigh the tractor before and after conversion.

Refuelling of the tanks is achieved by using two dispenser probes. To decrease fuelling time, one probe was modified to accept a 1/2 inch hydraulic-style coupling. Two 1/2 inch lines tee into a 3/8 inch line which supplies the tanks. Refuelling times for a typical fill of 150 kilograms are reported to vary from 10 to 20 minutes, depending upon the number of vehicles fuelling at the same time as the truck.

4.0 OPERATIONAL EXPERIENCE OF TRUCK

4.1 Overview of Operating History

The converted Cummins natural gas engine was installed in the Peace Wood Products logging truck at the end of January. During the first part of February some time was spent setting up the engine and curing a number of problems, mostly related to the cold weather conditions not foreseen by the converting firm in New Zealand.

The truck went back into full service in February 1989 and remained in operation until spring breakup in mid-March forced a halt to logging operations in the area. During the early summer the truck worked within Peace Wood Products' yard, hauling logs to the mill from outlying areas of the yard. Much of this work involved loads in the vicinity of 50,000 kg.

In the later part of summer, the truck returned to normal service, hauling logs from the woods to the mill. At this time Peace Wood Products offered to sell the truck to Centurion Fuels, as part of a general management policy to contract out log hauling to owner-operators. Centurion Fuels purchased the truck in July 1989, and has operated it since that time. Ownership of the truck has enabled the company to undertake more detailed research and closer monitoring of the engine.

To date (June 1990) the Centurion Fuels demonstration truck has accumulated more than 2200 hours of operating time on the natural gas engine, and has travelled about 88,000 kilometres.

4.2 Operational Experience

As in the case of virtually any other demonstration project involving a technology in the prototype stage, there have been a number of problems with the Centurion Fuel Systems truck. To date, the main problems related specifically to spark-ignition natural gas operation have been valve recession, engine misfiring due to ignition system problems, and problems with the Jacobs engine brake operation at low engine speeds. These problems are described in the following section, along with the measures taken to address them.

Valve recession: during August and September accelerated valve recession was experienced, increasing from 0.005 inch wear in 100 operating hours, to 0.013 inch in 50 hours. This eventually led to the removal of one cylinder head in an attempt to isolate the problem. A subsequent inspection revealed that soft valve seats had accidentally been installed during conversion of the engine in New Zealand. Considerable time was spent discussing with various manufacturers of Cummins parts the best combination of valves and seats available for use in natural gas engines.

At the end of October, three new heads were prepared using a harder valve and seat, combined with valve rotators, automotive style valve

stem seals, and powdered metal valve guides. The new combination has apparently proven successful to date, as valve recession has reportedly not been experienced over the last 500 hours.

Ignition system problems: the maintenance records from December 1989 to February 1990 indicate that engine misfiring has been a recurring problem. This misfiring has apparently resulted from accelerated spark plug wear and limited service life from the high-tension spark plug leads. It therefore has been necessary to frequently re-gap and replace spark plugs and also change high tension leads.

At present, a 12 mm x 19 mm automotive type spark plug is being used. Although the spark plug is performing with reasonable reliability, plug life between re-gapping is about 200 hours, or every 2 weeks. Centurion feels that a more acceptable goal for the re-gapping interval would be 500 hours, at which time normal engine maintenance of valves, oil, filter, etc. would be carried out. The company's research into spark plugs suggests that 500 hours between re-gapping might be achieved by changing from a 12mm to a 14 mm industrial-type spark plug. The latter type of plug is available in a broader heat range and offers the potential for superior heat dissipation. As the first stage in this work, an adaptor has been made that will accept 14mm x 1.25 threaded spark plugs.

A number of changes also have been made to the electronic ignition control box, the most significant being the use of components rated for temperatures below - 50^{o} C. Other changes have been the addition of a by-pass switch to eliminate operation of the engine brake below 1000 RPM, and smoothing chokes to control the switching on the ignition coils.

To make the engine acceptable for operation in explosive environments (i.e., in the event of a natural gas leak in the engine compartment), it is necessary to develop acceptable high tension leads and use shielded spark plugs compatible with the present ignition

system. This will involve some modification to the present spark plug adaptor sleeves and careful selection of spark plugs to maintain the correct heat range.

Engine compression brake: in the initial configuration of the converted engine, it was found that the engine brake could cause the engine to stall at low RPM under some circumstances. This problem was corrected by installing a relay in line with the power supply to the engine brake. At engine speeds of less than 1000 RPM, a signal from the ignition box opens the circuit in the relay, not allowing the engine brake to engage.

4.3 Driver Impressions

The driver of this truck has been running this unit ever since it was purchased by Peace Wood Products in 1977. He is thus well-qualified to appraise its comparative performance before and after conversion to natural gas fuelling. Centurion reports the following driver impressions:

1. The natural gas engine has a wider torque range than the former Detroit Diesel, allowing him to pull the engine down to a lower RPM on hills, this being very helpful in ice and snow conditions.

2. Power between the two engines is very similar, even with the Detroit being rated at 30 HP more than the Cummins on diesel.

3. Engine noise; in the cab has been reduced by a very noticeable amount, both during acceleration and during periods of extended use of the engine brake.

4. The effectiveness of the engine brake is the same as the Detroit Diesel, as well as the response time in turning the engine brake on and off during shifting.

5. Cold weather starting when left outside with the block and oil pan heater pugged in is the same as with the previous diesel engine.

6. Cold weather operation (-45^{O} to -50^{O} C outside temperatures) is more favourable on natural gas than on diesel, as the engine runs a more constant water temperature, varying as little as 10^{O} F when travelling on the highway empty.

5.0 FUEL CONSUMPTION MONITORING

5.1 Basis for Comparison

The truck in which the natural gas engine is installed is quite different from other logging trucks in several respects, as described earlier. In particular, it has a long trailer which cannot be piggybacked when empty and has a very low gearing which restricts its maximum road speed to about 90 kmh. For this reason, it is difficult to find a control vehicle against which to compare the fuel efficiency of the demonstration vehicle.

The ideal comparison would have been with a diesel engine of the same make and model as that converted to natural gas operation, and in the same type of truck operating on an identical duty cycle. Lacking such a control vehicle, however, the fuel efficiency of the truck operating with its Cummins 855 cubic inch, Big Cam II natural gas engine was compared with that of the same truck when it was engined with the original 1977 model 8V-92 Detroit Diesel.

A three-month period on natural gas operation from December 1989 to February 1990 was selected for comparison with a three-month period one year earlier when the truck was still powered by the 8V-92 Detroit Diesel engine. These three month-periods were selected because the truck was making an identical log haul during both periods. The haul consisted of 74 miles (119 km) of pavement north

from Fort St. John to Mile 115 on the Alaska highway, followed by up to 15 miles (24 km) of dirt logging road, for a total round-trip distance of 178 miles (287 km). Normally, the truck makes two round-trips per day, fuelling with natural gas after each trip. During the winter, the gross weight of the truck averages about 43,000 kg.

5.2 Comparative Fuel Consumption

Fuel consumption of the truck when it was operating on diesel fuel from November 1988 to January 1989 was verified by Canadian Resourcecon from the original log book of the truck, while natural gas consumption from December 1989 to February 1990 was verified from Computrol records of the Centurion natural gas fuelling station in Fort St. John. Minor adjustments were made to account for periods when the truck was undergoing testing on natural gas, rather than being used in its normal duty cycle.

This comparative fuel use information is summarized in Table 1. Both the diesel and natural gas fuel efficiency measures are very consistent from month to month, inspiring some confidence in the accuracy of the data. Natural gas is measured in kilograms, while diesel is measured in litres. In order to convert to a common unit of measure, the two fuels were equated on the basis of their lower heating values. Appendix A details the method of calculating the equivalency factor between kilograms of natural gas and litres of diesel fuel during the monitoring periods. In the Fort St. John service area of ICG Utilities, one kilogram of natural gas, on average, had a lower heating value equivalent to that of 1.40 litres of the grade of diesel fuel used during the respective monitoring periods on each fuel. This coefficient has been used herein. It should be noted, however, that this equivalency coefficient will change considerably on a seasonal basis as a result of changing diesel fuel pour point formulations. In the summer, this coefficient would be reduced to as low as 1.33 litres of diesel fuel per kilogram of natural gas.

On this basis, Table 1 shows that the truck averaged 3.72 miles per gallon, or 1.32 km per litre of diesel fuel equivalent while running on natural gas. This represents a loss in kilometres/litre of about 14 percent compared to when it was operating on diesel one year earlier. To express the relative fuel efficiency in another way, fuel consumption per unit of distance increased by approximately 16 per cent.

5.3 Relative Economics of Natural Gas Operation

In terms of relative fuel costs, other logging trucks hauling for Peace Wood Products are currently (March 6, 1990) able to purchase their fuel for 36 cents per litre, which is a fleet price. While the retail price for compressed natural gas at the Centurion Fuel Systems station is 39.9 cents per kilogram, a fleet price has not yet been established for large users such as the logging truck. For illustrative purposes, a price of 30 cents per kilogram has been used herein - an approximate estimate of the total cost of compressed natural gas for a fleet with its own compressor station.

Given these relative fuel prices, Table 1 shows that the truck would be saving more than 30 percent in fuel costs compared to when it was operating on diesel fuel.

TABLE 1: COMPARATIVE FUEL CONSUMPTION ANALYSIS
CENTURION FUEL SYSTEMS LOGGING TRUCK

NATURAL GAS FUEL CONSUMPTION SUMMARY (1)
DECEMBER 1989 TO FEBRUARY 1990

MONTH	Distance	Nat. Gas Used	FUEL EFFICIENCY MEASURES (kg of natural gas)			FUEL EFFICIENCY MEASURES (diesel equivalent basis)		
	Miles	kg	Miles/kg	km/kg	/100 km	Miles/gal	km/l	l/100 km
Dec	4,751	4,193.6	1.13	1.82	54.81	3.67	1.30	76.74
Jan	6,089	5,277.9	1.15	1.86	53.83	3.74	1.33	75.36
Feb	5,556	4,827.6	1.15	1.85	53.96	3.73	1.32	75.54
TOTAL	16,396	14,299.1	1.15	1.85	54.16	3.72	1.32	75.82

• Converted on basis of 1.40 litres of diesel fuel per kilogram of natural gas (see Table A-1).

DIESEL FUEL CONSUMPTION SUMMARY (2)
NOVEMBER 1988 TO JANUARY 1989

MONTH	Distance	Diesel Fuel Consumed		FUEL EFFICIENCY MEASURES (diesel equivalent basis)		
	Miles	gallons	litres	Miles/gal	km/l	l/100 km
Nov/88	6,346	1,451	6,596	4.37	1.55	64.48
Dec/88	4,162	972	4,419	4.28	1.52	65.86
Jan/89	5,017	1,162	5,282	4.32	1.53	65.31
TOTAL PERIOD	15,525	3,585	16,297	4.33	1.54	65.12

COMPARATIVE FUEL EFFICIENCY,
NATURAL GAS VERSUS DIESEL
(diesel equivalent basis)

Miles/gal	km/l	l/100 km
-14.1%	-14.1%	16.4%

COMPARATIVE FUEL COSTS, NATURAL GAS VERSUS DIESEL	DIESEL	NATURAL GAS	SAVINGS, GAS vs DIESEL $	SAVINGS, GAS vs DIESEL %
cts/kg		30.00		
cts/litre diesel equivalent	36.00	21.43		
$/1000 km	$234	$162	$72	30.7%

(1) Fuel consumption with 1977 Detroit Diesel 8V-92T, 430 HP engine.

(2) Fuel consumption with same truck re-engined with Cummins Big Cam II 400 NTC engine converted to spark-ignition operation.

APPENDIX A

NATURAL GAS AND DIESEL FUEL

ENERGY EQUIVALENCY AND EFFICIENCY DATA

APPENDIX A

NATURAL GAS AND DIESEL FUEL ENERGY EQUIVALENCY AND EFFICIENCY DATA

In order to calculate the relative fuel efficiency of the Centurion Fuel Systems demonstration truck on natural gas versus straight diesel, it was necessary to establish the heating values of the diesel fuel and natural gas consumed by the truck. There is considerable variation in the heating value of natural gas in different regions, while a substantial seasonal variation also exists in the heating value of summer versus winter grade diesel fuels. The project team therefore sought heating value data that pertained specifically to the natural gas and diesel fuel consumed by the truck. This information is summarized in Table A-1.

In establishing an equivalency between diesel fuel and natural gas, the lower heating value (LHV) is used as it provides a measure of the net amount of heat available to do useful work. This is in contrast to the higher heating value (HHV) which is a measure of the gross amount of heat before deducting the latent heat of the amount of water vapour produced from the hydrogen content of the fuel. Since the water vapour in the products of combustion is not condensed in the engine, the latent heat of vapourization is not available to perform useful work.

Westcoast Energy supplied monthly average natural gas quality data for the monitoring period (December 1989 to February 1990). The average specific gravity (relative to air) of the gas for this period was 0.595, while the HHV was 39.84 MJ/m3. Given that the weight of air is 1.2250 kg/m3, the natural gas had a HHV of 54.69 MJ/kg. This translates into a LHV of 49.28 MJ/kg, based upon the ratio of LHV/HHV calculated for a typical gas composition.

The oil distributor supplying Peace Wood Products with diesel fuel during November 1988 to January 1989, stated that the truck would have been using -39 degrees Centigrade pour point diesel during this period. The estimated HHV of this grade of fuel produced at the Taylor refinery during these months was is shown in Table A-1, along with corresponding heating values

for natural gas during the winter of 1989/90. The HHV for diesel fuel averaged about 37.53 MJ/litre during the period from November 1988 to January 1989. This translates into a LHV of about 36.93 MJ/litre, based on the relationship between API Gravity and LHV/HHV ratios derived from ASME Power Test Codes.

On the basis of the data shown in Table A-1, the LHV of one kilogram of natural gas would be equal to about 1.40 litres of Interior winter grade fuel during the respective monitoring period on each fuel. It should be noted, however, that this coefficient will change considerably on a seasonal basis as a result of changing diesel fuel pour point formulations. In the summer, this coefficient could be reduced to as low as 1.33 litres of diesel fuel per kilogram of natural gas.

TABLE A-1: NATURAL GAS AND DIESEL FUEL ENERGY EQUIVALENCY DATA

NATURAL GAS QUALITY DATA, FORT ST. JOHN

YEAR	MONTH	SPECIFIC GRAVITY	MJ/m3 HHV	MJ/kg* HHV	MJ/kg** LHV
1989	Dec	0.598	40.01	54.62	49.21
	Jan	0.594	39.78	54.67	49.25
	Feb	0.592	39.74	54.80	49.37
	AVG	0.595	39.84	54.69	49.28

SOURCE: Specific gravity and HHV/m3 obtained from Westcoast Energy.

* Based on air density of 1.225 kg/m3 x specific gravity x HHV/m3.

** Based on LHV/HHV ratio of 0.9009, as calculated below. LHV = lower heating value; HHV = higher heating value.

LHV/HHV RATIO OF PRINCIPAL NATURAL GAS COMPONENTS

COMPONENT	% TOTAL	LHV/ HHV	WEIGHTED LHV/ HHV*
Methane	95.50%	90.04%	86.86%
Ethane	3.00%	91.47%	2.77%
Propane	0.50%	92.00%	0.46%
TOTAL	99.00%		90.09%

* Re-weighted as a percentage of the total of the three principal constituents. The remaining one percent of natural gas is primarily nitrogen and carbon dioxide, which have no heating value.

PETRO CANADA DIESEL FUEL QUALITY*

	Pour Point 'C	API Gravity	HHV Btu/gal	HHV kJ/litre	LHV/ HHV	LHV kJ/litre
Nov. 1988	-39	41.5	161,850	37,561	0.937	35,195
Dec. 1988	-39	41.4	161,920	37,577	0.937	35,210
Jan. 1989	-39	42.1	161,430	37,463	0.937	35,103
AVG.	-39	41.7	161,733	37,534	0.937	35,169

* API gravity and HHV (higher heating value) obtained from Petro Canada refinery at Taylor, B.C. HHV's are calculated based upon ASME Power Test Codes, as is ratio of LHV/HHV.

AVERAGE NATURAL GAS/DIESEL EQUIVALENCY FACTOR

	Avg. LHV	
Natural gas	49.28	MJ/kg
Diesel fuel	35.17	MJ/litre
Equivalence	1.40	litres of diesel per kg of natural gas at equal thermal efficiency